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American Heart Journal

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Original Communications

HYDRODYNAMICS IN VENTRICULAR SEPTAL DEFECTS

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WHILE animal experimentation and cardiac catheterization have provided considerable information concerning the flow patterns in ventricular septal defects,[1-10] examination of the available data demonstrates difficulties in adequate interpretation of the hemodynamics with these methods.

Hydraulic analysis utilizing specially designed models of this anomaly may contribute to the explanation of some of the clinical and pathologic findings in these conditions. An integrated circulation model developed in this laboratory[11-13] provided an opportunity to study the dynamic effects of ventricular septal defects of varying size. The presence of superimposed "pathology" such as valvular lesions, as well as certain of the phasic variations in flow across the defect, were also studied.

This model has been shown to have suitable qualities for studies of cardiodynamics, since it follows Starling's law of the heart, and provides data consistent with the various conditions which may be tested in it, such as valvular stenoses and insufficiencies, "congestive failure" and other states.

While the data obtained with such models represent an approach to only the mechanical problems involved, they do provide a systematic analysis of potential hydraulic aspects of ventricular septal defects in various simple and complicated conditions. The results to be presented focus attention on several aspects not previously appreciated, such as the nature of the diastolic shunts, the atrial pressure changes, and the important role of the level of the systemic peripheral resistance.

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METHODS

The circulation model was so designed that fluid passed, as in the mammalian circulation, from the right atrium to the right ventricle, then through a low resistance pulmonary circuit to the left atrium and ventricle. From the left ventricle the fluid was pumped into the aortic system through a peripheral resistance, returning by way of a vena cava to the right atrium (Fig. 1).

In appropriate phases of the study, the two ventricles were connected by a short length of plastic tubing which acted as a ventricular septal defect. The size of the defect was varied by means of a screw clamp applied to the interventricular connection. Similar screw clamps varied the systemic peripheral resistance, thereby controlling flow from the aorta. Pulmonary vascular resistance was increased by applying spring clamps to the "capillaries" of the pulmonary manifold.

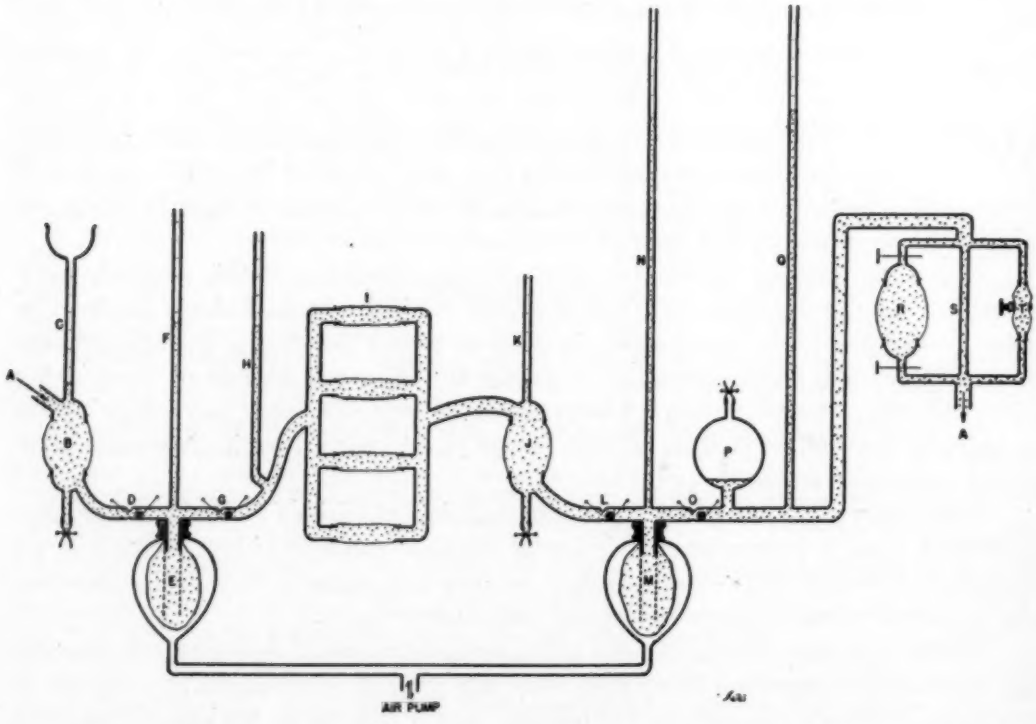

Fig. 1.—Design of the circulation model. Venous return (*A*) enters the right atrium (*B*) and flows by gravity past the tricuspid valve (*D*) to the right ventricle (*E*). With ventricular systole, fluid is ejected through the pulmonic valve (*G*) into the lung manifold (*I*) and thence to the left atrium (*J*). After passing through the mitral valve (*L*) into the left ventricle (*M*), the fluid is ejected through the aortic valve (*O*) into the systemic circulation. In the present experiments the entire peripheral resistance was controlled by a screw clamp compressing the outflow at a point above the cross tube (*S*). The venous return leaves the systemic manifold at (*A*) and returns to the right atrium (*B*).

Manometers attached to each chamber of the circulation permitted the measurement of pressures (see *C*, *F*, *H*, *K*, *N*, *Q*). *P* represents the elasticity, or surge tank characteristics, of the aortic system.

Ventricular septal defects were produced by a tubular connection between the cross tubes over each ventricle. Flows were measured by rotameters connected to the ventricular defect and at a point between *O* and the systemic manifold. Contraction of the ventricles was achieved by means of an air pump which intermittently increased the air pressure in the glass leveling bulb (smooth lines) surrounding each ventricle (irregular thin lines). From Rodbard, S.: J. Lab. & Clin. Med., August, 1951.

Each of the heart valves of the model could be adjusted to produce a stenosis or insufficiency. Stenosis was produced by pressing a spring against the steel ball of the ball-valve arrangement, preventing it from opening fully. Specified degrees of stenosis could be produced by varying the pressure on the ball, the degree of narrowing being indicated by the pressure gradient across it. Insufficiency was produced by advancing a stylus which prevented the ball from being seated in the valve, thereby permitting regurgitant flow.

The ventricles were made of commercially available thin-walled latex rubber. The atria did not contract. Ventricular filling occurred by gravity and was a function of the atrial pressure head and the duration of diastole.

The ventricular rate was regulated at 18 or 20 contractions per minute by means of a windshield wiper motor operating on compressed air. This slow rate was selected in order to allow adequate ventricular filling, as well as to permit more accurate observation and recording of the cyclic changes in pressure and flow. Diastole was arbitrarily set at a period of time somewhat shorter than that of systole.

Cyclic entrance of compressed air into the glass jackets surrounding the ventricles produced successive contractions. The strength of the ventricular contraction was adjusted by means of a stopcock which controlled the flow of air into the glass jackets; this was adjusted so that complete emptying of the ventricles took place during each cycle.

Pressures were measured by means of water manometers connected directly to the pulmonary artery, aorta, and to each of the heart chambers. Shunt flow and systemic flow were usually measured visually by direct-reading rotameters. In some experiments the flow through the shunt and the ventricular pressure tracings were recorded on a Sanborn Polyviso, using an electrical recording rotameter and strain gauge pressure manometers. The values for shunt flow calculated by this method were greater than those recorded visually by reading of the float rotameters. However, changes in flow were qualitatively the same under all experimental conditions.

Before creating ventricular defects or other abnormalities, the model was first adjusted to obtain a "normal" base-line circulation. This "normal" circulation varied slightly in the various series of studies. However, it was maintained constant in each experiment in which the shunt flow and ventricular pressures were obtained by strain gauge manometers and an electric recording rotameter. These values are tabulated with each set of data. A slight pulmonic stenosis, inherent in the circulation model which we used, was present throughout.

RESULTS

I. *Left to Right Shunts.—*

Production of a ventricular septal defect (VSD): On opening the ventricular septal defect, several striking changes occurred within a beat or two. A large left-to-right shunt developed, so that the left ventricle ejected almost half of its output through the defect and right ventricle into the pulmonary artery (Fig. 2). The enhanced pulmonary flow caused an elevation of left atrial pressure and this, in turn, brought about a retrograde rise in right ventricular sys-

tolic pressure and in the pulmonary arterial pressure. Reductions in aortic, left ventricular, and right atrial pressure reflected the decreased systemic flow. The ventricular pressures tended to approach a mean. These results are summarized in Table I.

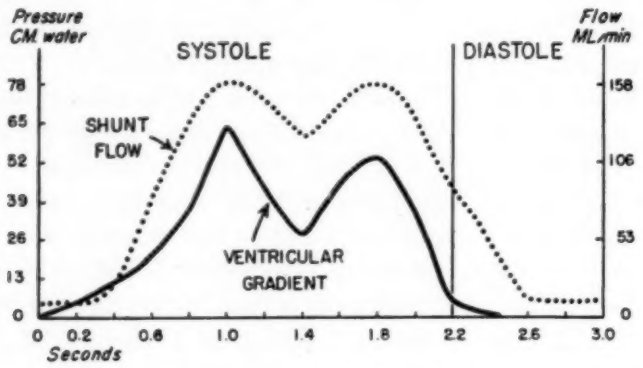

Fig. 2.—Relation between shunt flow and ventricular pressure gradient in model with moderate ventricular septal defect. A single cycle is given. The pressure gradient between left and right ventricle is given as ordinate at left, and is shown by the solid line. In the ordinate scale at the right, the flow across the shunt is given as the dotted line. These data were taken from direct recordings of rotameters and electromanometers. (Note the early diastolic shunt.)

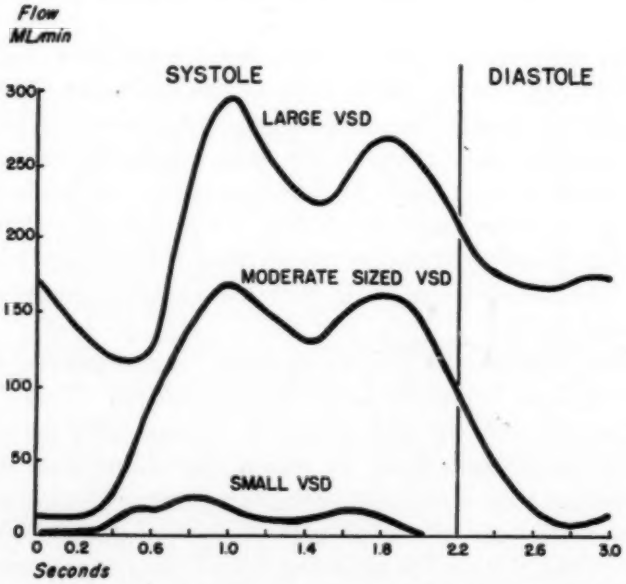

Fig. 3.—Shunt flow in three sizes of VSD. Convention as in Fig. 2. In the small VSD, flow is minimal and there is no diastolic shunt. In the moderate size VSD, the shunt is predominately systolic, with an early diastolic shunt. With the large shunt, an appreciable diastolic flow is present in addition to that during systole.

Variations in the size of the VSD: Adjustment of a screw clamp on the tubing connecting the two ventricles made it possible to vary the size of the defect. The change from normal chamber pressures, systemic flow, shunt flow, and aortic and pulmonary arterial tension were, as expected, related to the size of the interventricular orifice.

With a small connection, the hydraulics were only slightly altered. The pressure gradient remained high, and the shunt flow and other measurements approached those in the normal state (Fig. 3). The interventricular pressure gradient was reduced with a moderate size of the connection and the systolic shunt was greater.

Large ventricular septal defects showed not only a significant increase in systolic left-to-right shunt, but also demonstrated an unexpected diastolic shunt (Fig. 3). This shunt was associated with a rise in left atrial pressure (Table I). The aortic pulse pressure varied directly with the systemic flow. Since the large defect caused the most marked reduction in forward ejection, it was also associated with the lowest systemic pulse pressure.

TABLE I. PRESSURES AND FLOW IN VSD WITH ASSOCIATED VASCULAR ABNORMALITIES

	RAP*	RVP†**	PAP‡	LAP§	LVP‖**	A_oP#	SHUNT FLOW (ML./MIN.)	SYSTEMIC FLOW (ML./MIN.)
"Normal"	20/10	65/0	36/14	28/12	105/0	105/67	0	350
Moderate VSD	20/10	70/0	40/22	32/16	108/0	83/55	80 (l ⟶ r)	280
Large VSD	16/9	72/0	47/30	38/25	93/0	79/50	60 (l ⟶ r)	290
VSD + "normal" systemic pressure	13/8	70/0	45/30	37/25	99/0	94/68	75 (l ⟶ r)	240
VSD + systemic hypertension	4/2	75/0	55/30	39/30	120/0	130/110	120 (l ⟶ r)	120
VSD + AS	8/6	80/0	55/30	40/34	135/0	37/25	260 (l ⟶ r)	160
VSD + AI	12/9	70/0	52/30	40/32	83/0	58/18	160 (l ⟶ r)	170
VSD + MS	8/6	64/0	44/36	38/33	63/0	50/27	10 (l ⟶ r)	160
VSD + MI	10/8	70/0	50/30	40/35	70/0	45/25	60 (l ⟶ r)	160
VSD + PS	23/12	155/0	16/9	14/8	118/0	118/80	90 (r ⟶ l)	400
VSD + increased pulmonary resistance	20/10	140/0	160/140	3/2	90/0	100/70	55 (r ⟶ l)	380

Pressures are given in centimeters of water.
*Right atrial pressure.
†Right ventricular pressure.
‡Pulmonary arterial pressure.
§Left atrial pressure.
‖Left ventricular pressure.
#Aortic pressure.
**Because of the construction of the model it was not possible to measure the diastolic pressure in the ventricles. It may be assumed that the diastolic pressures were similar to those in the atria.

VSD plus "normal" or increased aortic diastolic pressure: Since the systemic arterial pressure in most patients with VSD is usually within normal limits rather than being very low, we investigated the effect of maintaining the aortic diastolic pressure at the level existing prior to production of the defect. The screw clamp which controlled the systemic peripheral resistance was tightened until the aortic pressure was returned to preshunt levels. This effected a further rise in left-to-right shunt flow and a sharp fall in systemic flow (Table I). Only a slight further decrease in right atrial pressure was recorded.

While the maintenance of the preshunt level of aortic pressure did cause some increase in shunt flow and diminution in systemic output, these changes were not marked. However, further raising of the systemic resistance with the

production of systemic hypertension caused the shunt flow approximately to double, while the systemic output fell precipitously.

VSD plus aortic stenosis: The degree of aortic stenosis induced by the technique described above was estimated by the gradient in pressure between the left ventricle and the aorta. There was little change in pressure or flow until the narrowing of the aortic ostium reached a critical point. At this time the left ventricular pressure increased significantly. The left-to-right shunt then increased by almost 50 per cent (Fig. 4), while the systemic output fell to low values. The enhanced left-to-right shunt was reflected in rising pressures in the left atrium, pulmonary artery, and right ventricle. The rise in left ventricular pressure outdistanced that in the right ventricle, so that a heightened pressure gradient was produced. With the decline in systemic output there was a fall in venous return and right atrial pressure. The results are given in Table I.

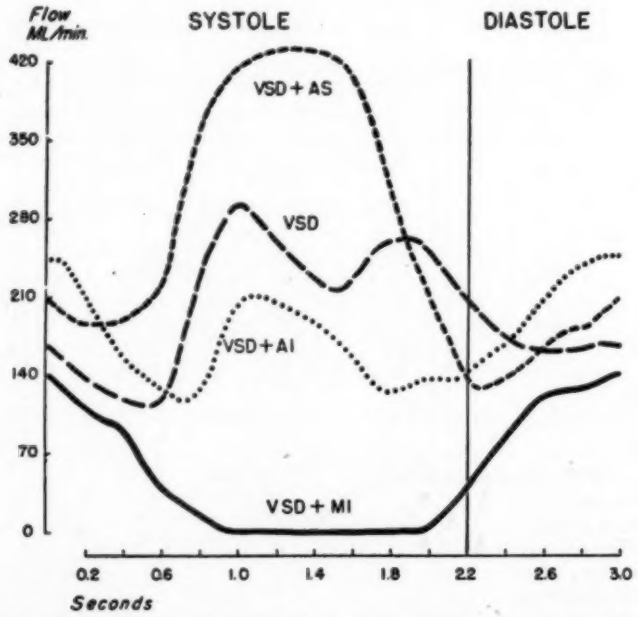

Fig. 4.—Effect of various valvular lesions on shunts in ventricular septal defect. The ordinate gives rates of flow in milliliters per minute. The broken trace labeled *VSD* is the curve for a large VSD as in Fig. 3, and is used for comparison. The trace labeled *VSD + AS* represents the addition of aortic stenosis; in this instance the systolic shunt is markedly enhanced, while a large diastolic shunt continues. The curve labeled *VSD + AI* represents the effect of aortic insufficiency as the second lesion; in this instance the systolic shunt is reduced somewhat, but the diastolic shunt is enhanced, being among the greatest recorded. The lowest curve, *VSD + MI*, represents the combination with mitral insufficiency; the systolic shunt is markedly reduced, but the diastolic shunt is very great. (Discussed in text.)

VSD plus aortic insufficiency: With an intact ventricular septum, aortic insufficiency resulted in a reduced aortic-diastolic pressure and a heightened pulse pressure. The left ventricular diastolic volume and pressure increased because of the regurgitation, and the left atrial pressure began to rise.

These effects were enhanced in the presence of a VSD. Aortic insufficiency reduced the systolic left-to-right shunt (Fig. 4), but a considerable left-to-right shunt was present during diastole. These data are summarized in Table I.

VSD plus mitral stenosis: The expected effects of mitral stenosis were markedly enhanced after induction of a VSD. A considerable distention of the left atrium and reductions in the left ventricular end-diastolic volumes were observed. As a consequence, the aortic pressure and output fell while the volume of the shunt was decreased. These data are given in Table I.

VSD plus mitral insufficiency: In mitral insufficiency the left ventricle had three potential outlets: the normal route into the aorta, and the two abnormal pathways of the right ventricle and the left atrium. In the presence of a large VSD, the volume of the systolic left-to-right shunt fell precipitously when mitral insufficiency was produced, with no shunt taking place during much of systole. Simultaneous pressures obtained from the left and right ventricles revealed no significant pressure gradient during systole. However, the left-to-right shunt was marked during diastole (Fig. 4).

II. *Right to Left Shunts.*—

VSD plus pulmonic stenosis: The degree of pulmonic stenosis was estimated by the gradient between the right ventricular and pulmonary arterial pressures (Table I).

In the presence of a large VSD, pulmonic stenosis tended to balance the forces producing the left-to-right shunt. When the pulmonic stenosis was made sufficiently severe, the shunt reversed and passed from right to left. In the presence of a large defect, the magnitude, as well as the direction of the shunt, was seen to depend upon the relative resistances to output into the aorta and into the pulmonary artery.

VSD plus increased pulmonary vascular resistance: An increase in resistance to flow through the lungs could also be produced by placing spring clamps on the thin-walled "capillaries" of the pulmonary circuit. Placement of such a resistance caused the pulmonary arterial pressure to rise until it equaled, and finally surpassed, the aortic pressure. As expected, the right ventricular systolic pressure also increased progressively, causing the volume of the left-to-right shunt to diminish, cease, and finally reverse (Table I). With reversal of the shunt, both ventricles began pumping into the aorta, systemic output increased, and the pressures in the left ventricle and aorta were elevated. The increase in systemic venous return caused the *right* atrial pressure to rise, while the decline in pulmonary flow resulted in a fall in left atrial pressure and a reduction in the size of this chamber.

III. *Diastolic Shunts.*—Examination of flow patterns in VSD showed that shunts of considerable magnitude may occur during diastole (Figs. 3 and 4). Diastolic shunting was absent when an uncomplicated VSD was small, minimal when the defect was of moderate size, but was dynamically very important when the defect was large.

Examination of the pressure changes in the atria provided an explanation for the diastolic shunting. In a widely patent VSD with a large systolic left-to-right shunt, the marked increase in pulmonary flow and in the volume delivered to the left atrium caused distention of this chamber and a marked pressure rise in it, especially during systole of the left ventricle.

With the opening of the atrioventricular valves during diastole, the four chambers of the heart became a functional single chamber. Since, at this time in the cycle, the pressure in the left atrium was considerably greater than that in the right atrium (23 cm. water compared with 9 cm. water), flow took place from the left atrium across the septal defect to the right ventricle, effecting a diastolic left-to-right shunt.

In the presence of an uncomplicated large VSD the diastolic shunt was almost as great as the systolic shunt (Fig. 3). In insufficiency of the mitral or aortic valves, the diastolic shunts equaled or even exceeded the systolic shunts. In aortic insufficiency the diastolic shunt was caused not only by the elevated left atrial pressure but also by the aortic regurgitation into the left ventricle with a resultant increase in left ventricular diastolic pressure.

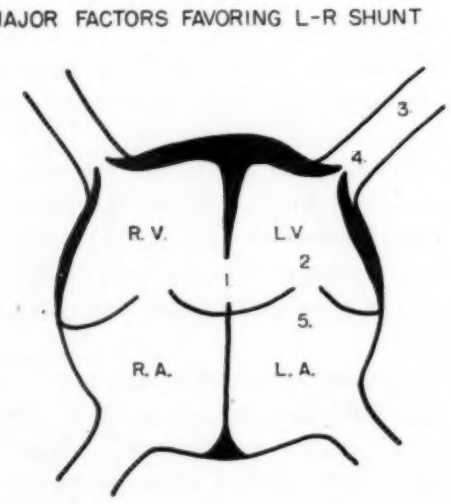

Fig. 5.—Schema illustrating major factors in left-to-right shunts. *R.V.* represents right ventricle; *L.V.*, left ventricle; *R.A.*, right atrium; *L.A.*, left atrium. *1* represents the VSD which, by its area, determines the tendency to shunt; *2* represents the volume of diastolic filling of the left ventricle; *3* represents the effect of systemic hypertension, and *4* represents that of aortic stenosis; and *5* represents the pressure in the left atrium.

Diastolic right-to-left shunts were observed in the presence of pulmonic stenosis and/or pulmonary vascular hypertension. However, these shunts occurred only when the aortic pressure was relatively low. The shunts during both systole and diastole were in the same direction in all the relatively "simple" conditions given above.

Certain more complex situations were investigated in which bidirectional diastolic shunts were observed. For example, when there was a simultaneous aortic insufficiency and a marked increase in pulmonary vascular resistance, the shunt was right-to-left during systole and left-to-right during diastole. In other studies, anatomical overriding of the aorta produced bidirectional shunts.[30]

IV. *Pressure Gradients.*—The temporal relationships of shunt flow and ventricular pressure gradients in the presence of a VSD of moderate size are shown

in Fig. 5. It can be seen that, for a given size of the communication, the volume of shunt flow closely paralleled the pressure gradient, being greatest when the pressure gradient was most marked. However, the presence or absence of a gradient could not be correlated with the volume of the shunt since, with larger orifices, the gradient was less despite an enhanced flow. Similarly, with small defects, the gradient would be large with little shunt. A pressure gradient could still be produced in the presence of a large VSD by introducing a secondary lesion, such as aortic stenosis.

V. *Effect of an Increase in Circulation Volume.*—The preceding studies were undertaken under "acute" conditions, that is, when a VSD was introduced into a "normal" circulation, as might occur clinically in rupture of the ventricular septum following myocardial infarction.

The common forms of ventricular septal defect, however, are chronic disorders in which adaptations such as an increase in blood volume have taken place. It was felt that additional information might be obtained if fluid were added to the model in order to simulate the increase in circulating blood volume which occurs in patients with VSD of long duration.

In the normal circulation model (circulating volume of about 600 ml.) the addition of approximately 200 ml. of fluid resulted in an increase in flows and pressures throughout all portions of the circulation model. When a VSD was present, the addition of similar amounts of fluid produced a rise not only in systemic flow and in all pressures, but it also enhanced the left-to-right shunts. Pulmonary flow was therefore increased to a marked degree. It is worth noting that the left atrial and pulmonary arterial pressure increases were of considerable magnitude (Table II). An increase in circulating fluid volume in the presence of right-to-left shunts enhanced this shunt and tended to increase the forward output.

TABLE II. THE EFFECT OF AN INCREASE IN CIRCULATING FLUID VOLUME

	RAP	RVP	PAP	LAP	LVP	AoP	SHUNT FLOW (ML./MIN.)	SYSTEMIC FLOW (ML./MIN.)
"Normal"	8/6	60/0	30/10	10/4	110/0	110/70	0	450
Large VSD	7/4	70/0	40/10	29/10	100/0	84/55	70 (l ⟶ r)	340
VSD + fluid	13/6	90/0	55/24	38/22	120/0	105/74	100 (l ⟶ r)	430
"Normal"	20/11	68/0	36/14	28/14	105/0	110/70	0	360
Large VSD + increased pulmonary resistance	20/10	140/0	160/140	3/2	90/0	100/75	55 (r ⟶ l)	380
VSD + increased pulmonary resistance + fluid	20/10	145/0	170/150	3/2	85/0	100/70	75 (r ⟶ l)	400
"Normal"	20/11	75/0	38/18	29/12	105/0	110/70	0	360
Large VSD + PS	20/10	150/0	25/14	24/12	110/0	115/70	50 (r ⟶ l)	360
VSD + PS + fluid	28/22	160/0	35/20	32/20	135/0	150/105	70 (r ⟶ l)	500

All pressures and flows were recorded visually.
Conventions as in Table I.

DISCUSSION

The present studies illuminate certain relationships in the hydrodynamics of VSD. These are discussed below in terms of specific problems.

Small defects: In VSD, each ventricle has two orifices competing for its stroke volume. When the defect is small, the ventricular orifice offers major resistance to flow and only a small volume can shunt across it. The left ventricle then loses a small, but definite, volume to the right ventricle, but the rapid increase in intraventricular pressure permits the major portion of the stroke output to pass into the aorta, and the dynamic disturbance of the circulation is minimal. As expected, the interventricular pressure gradient remains high.

Large defects: With larger defects the resistance that the septal orifice offers to flow is much less. The volume of the shunt increases with the area of the orifice, and the ventricles act more and more like a single pumping chamber, with the ventricular pressures approaching a mean (Fig. 5). The quantity of the shunt across the defect is no longer limited primarily by the interventricular pressure gradient, since this is virtually obliterated. Instead, the direction and volume of the shunt depends upon the relative resistances to outflow offered by the pulmonary circuit and by the aortic circuit.

The normal pulmonary circulation is a vascular bed of low resistance, and massive flow may take place through it at relatively low pressures.[14]

Excessive flow will tend to raise the pressure in the pulmonary capillaries and thereby bring about the danger of transudation across these ultrathin vessels, leading to pulmonary edema. Protective factors may represent themselves as a stenotic orifice at the pulmonary ostium, by hypertrophy of media and intima of the arterioles, or by the use of a ventilatory positive pressure mechanism.[15]

Potential variability of defect: While the experiments on a model may reveal shunts of great magnitude, it must be pointed out that, in the human heart, cyclic variations in the size of the defect may influence the quantity of blood being shunted. For example, contraction of muscle rings around the defect may reduce its size during systole. Evidence for similar changes in the size of an orifice has recently been demonstrated at the mitral ring, and at pulmonary infundibular stenosis in man.[16]

Systemic vascular resistance: The level of systemic arterial pressure can produce a rather marked effect on the magnitude of the shunt (Fig. 5). For example, systemic hypertension enhances the left-to-right shunt, thereby producing an additional mechanical burden for the lesser circulation while decreasing the vital systemic flow. Such an effect of hypertension in ventricular septal defects would, therefore, be more deleterious than a similar elevation in systemic resistance in the presence of an intact ventricular septum.

By contrast, systemic hypotension (i.e., reduced peripheral resistance) reduces the magnitude of the shunt, relieves the right ventricle of some of its work load, and reduces pulmonary congestion and left atrial pressure, and increases systemic flow.

Examination of the systemic blood pressure of patients with VSD and large left-to-right shunt reveals a tendency to low pressure levels. No instances of

systemic hypertension in such congenital anomalies were found in the literature, perhaps because the combination of a high systemic resistance with a large or moderate VSD would produce overwhelming circulatory failure.

The present analysis, therefore, suggests that the maintenance of a low systemic resistance in such patients may be of value. It should be noted that a diminution in shunt flow resulting from systemic hypotension would bring about an increase in forward output, acting as a kind of autotransfusion. It is quite likely that, as in the model, suitable manipulation of the systemic vascular resistance by vasoactive agents in man may give information concerning the locus and magnitude of the shunt under various conditions.

The systemic pulse pressure of the model tended to be reduced in left-to-right shunts, while normal or slightly increased pulse pressure was found in right-to-left shunts. However, these tendencies probably are not clearly demarcated clinically because of the considerable variations in the magnitude of the shunt and of other complicating factors.

MAJOR FACTORS FAVORING R-L SHUNT

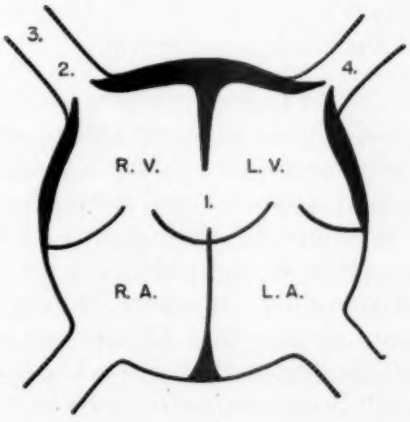

Fig. 6.—Schema illustrating major factors in right-to-left shunts. Conventions as in Fig. 5. *1* represents the area of the VSD; *2* and *3* indicate the sites of pulmonic stenosis and hypertension, respectively; and *4* the effects of a low systemic resistance.

Aortic stenosis: By producing an impediment to normal outflow from the left ventricle, aortic stenosis resulted in a substantial increment in left-to-right shunt. The septal defect, presented with an increased flow across it, then began to offer resistance to flow, and a large ventricular pressure gradient developed. The VSD evidently becomes a much more serious lesion in the presence of aortic stenosis, as it must in the presence of systemic hypertension, since a large part of the forward output is shunted into the lesser circulation (Fig. 5).

Pulmonic resistance: Pulmonic stenosis or elevated pulmonary vascular resistance creates impediments to outflow into the pulmonary circuit and, therefore, tends to reduce the size of the left-to-right shunt. As the pulmonic resistance becomes more severe, relative to the resistance offered at the aortic out-

let, the shunt reverses and then passes from right to left (Fig. 6). Since the direction and magnitude of the shunt, in large- or moderate-sized VSD, depend upon the balance between the systemic and pulmonary resistances, stabilization of the resistance at the pulmonary orifice, as occurs with pulmonic stenosis, has the interesting effect of causing the systemic vascular resistance to become an important regulator of shunt flow. Thus, a decrease in systemic resistance may cause the pulmonary resistance to become relatively the greater of the two, and the shunt may be reversed, causing a by-pass of the lungs with resultant cyanosis. A case with similar findings during systemic vasodilatation has been presented by Hamilton and associates.[17]

Aortic insufficiency: The low aortic diastolic pressure of aortic insufficiency provides a reduced systemic resistance against which the ventricles must pump, especially during the first part of systole (Fig. 5). The left ventricle thus meets a reduced resistance to ejection into the aorta, and the systolic left-to-right shunt is diminished. However, the regurgitation from the aorta during diastole causes the left ventricular filling pressure to be higher than that in the right ventricle. This may produce a diastolic left-to-right shunt; if such a shunt is already present, it will be amplified. The net effect is a slight decline in over-all left-to-right shunt. Mechanically, the left ventricle has a greater volume load to deliver during systole because of the aortic regurgitation.

Mitral insufficiency: Three orifices compete for the left ventricular output in mitral insufficiency: the mitral and aortic valves, and the septal defect itself. Since the left ventricle loses some of its volume to the left atrium, the stroke output tends to be reduced, and a much lower systolic pressure results, tending to equalize the ventricular pressures.[13] The quantity of blood shunted across the defect during systole can become negligible, and the forward output into the aorta may diminish considerably. However, during diastole the distended left atrium, with a pressure considerably higher than that in the right atrium, rapidly fills the left ventricle and then effects a left-to-right diastolic shunt, the over-all left-to-right shunt being markedly reduced. Although partially correcting the deleterious effects of the left-to-right shunt, mitral insufficiency can rob the systemic circuit of a significant part of its output.

Mitral stenosis: By reducing left ventricular filling, mitral stenosis makes less fluid available for ejection, and both systemic and shunt flows decrease considerably.

Plethora: An increase in circulating volume in ventricular septal defects[18-19] brings about a rise in the size of the shunt, but it also markedly enhances the systemic output. Even though an expanded circulating volume may increase the work load which the heart is called upon to perform, the proportionately greater forward output which results could improve the general circulatory status of the individual.

Transfusions, therefore, may not only increase the volume of the shunt and lead to pulmonary congestion, but also may enhance the vital systemic flow and act as a protective mechanism which ensures adequate forward delivery.

Diastolic shunt: If the VSD is large, a diastolic shunt of considerable magnitude may occur, moving in the same direction as that during systole. It must be appreciated that relatively great flow can take place through an orifice at very low pressure heads. The data suggest that if incompetence of the right ventricle or pulmonic insufficiency develops, the ensuing elevation of diastolic pressure might bring about a diastolic right-to-left shunt, even though the systolic shunt be in the opposite direction.

The studies suggest that the diastolic murmur sometimes heard in VSD[20-23] may be caused by either a relative mitral stenosis due to the enhanced flow during diastole from left atrium to left ventricle, or possibly may result from the diastolic shunt across the defect itself.

Mechanism of pulmonary hypertension and vascular changes: The mechanisms of pulmonary hypertension in the Eisenmenger-like complex and the etiological factors in the pathologic changes in the pulmonary arterioles are still under intensive study.[24-29] Certain facts have been established which may have a bearing on this problem. In a large VSD there is frequently a slight increase in the size of the left atrium. The left atrial pressure rises after the acute production of a VSD in dogs.[4] The present model experiments suggest that the hydraulic basis for this increase in left atrial pressure and volume may be due to the rapid movement of an increased right ventricular output through the lungs, returning to the left atrium within a short time.

A review of cardiac catheterization records at this hospital also shows that two patients with Eisenmenger-like complex and predominant left-to-right shunt had elevated pulmonary wedge (presumptive left atrial) pressures (13 and 14 mm. Hg, respectively). It may be suggested that an increase in the pressure in the pulmonary veins and left atrium may be associated with changes in the resistance to flow through the pulmonary arterioles, producing a generalized pulmonary vascular hypertension. The changes in the pulmonary arterioles which are seen in VSD and in patent ductus arteriosus may possibly, thus, have their origin in mechanisms similar to those responsible for the changes in chronic mitral stenosis.

SUMMARY

The hydraulics responsible for shunt flow in ventricular septal defects (VSD) were studied in a specially designed model which permitted adjustment of the size of the defect, changes in the volume of circulating fluid, and changes in the resistances to inflow and outflow of the several heart chambers.

With a *small* VSD, the cross-section area of the orifice was the controlling factor in the volume of the shunt, even though a high pressure gradient between the two ventricles was present. Since the volume of the shunt was thereby limited, little or no dynamic effects were impressed on the circulation as a whole.

VSD's of *large* size permitted the development of a large shunt with a tendency toward equalization of the pressures in the two ventricles. The factors controlling the volume of the shunt and its direction then depended upon the resistances to outflow from the functional single ventricle. A high resistance to outflow into the aorta, such as may occur in systemic hypertension or in aortic stenosis, enhanced the volume of the left-to-right shunt.

In the presence of a large left-to-right shunt, the increased volume delivered to the left atrium caused a pressure increase in, and distention of, this chamber. This high left atrial pressure was reflected in an increased filling pressure of the left ventricle during diastole. When the atrioventricular valves opened at the onset of diastole, all four chambers of the heart were functionally united, and the high left atrial pressure produced a diastolic shunt across the defect.

A high resistance to outflow into the pulmonary circuit, such as occurs in pulmonic stenosis or increased pulmonary vascular resistance, reduced the shunt and, when severe enough, caused its reversal.

Augmentation of the volume of circulating fluid produced striking effects on the circulation. Pressures in all parts of the circulation model were increased, as was the cardiac output. When a VSD was present, an increase in the volume of circulating fluid not only augmented the left-to-right shunt, but also increased the forward output. This increase in the volume of the circulating fluid, although mechanically disadvantageous, could be shown to tend to improve the "physiological" function.

Insufficiency of the aortic or mitral valves increased the volume of the diastolic left-to-right shunt. Mitral stenosis produced a complex of effects leading to severe generalized pulmonary vascular hypertension and a reduced forward output.

The data obtained with the model provide a mechanical basis for the study of the dynamics of VSD, and an explanation for certain findings, such as diastolic murmurs and enlargement of the left atrium. They suggest that important clinical information may be obtained in VSD by appropriate manipulation of the systemic resistance.

SUMMARIO IN INTERLINGUA

Le hydraulica del defectos ventriculo-septal esseva studiate in un modello que permitteva un varietate de adjustamentos. Pro parve defectos, le factor dominante in le regulation del fluxo derivational esseva le section transverse del defecto. In large defectos, le derivation esseva regulate primarimente per le resistentia relative incontrate per le fluido effluente a in le systemas pulmonar e aortic. In le presentia de large derivationes sinistro-dextere systolic, un augmentate pression in le atrio sinistre provocava un derivation sinistro-dextere diastolic. Le augmentation del fluido circulante augmentava non solmente le derivation sed etiam le ejection in avante. Le datos colligite pare indicar que information clinic in re le natura del derivation in patientes human es probabilemente obtenibile per manipular le resistentia vascular systemic o le volumine circulante.

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RIGHT HEART PRESSURE PATTERNS IN CONSTRICTIVE PERICARDITIS

Mechanism of Formation and Significance

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THE characteristic right heart pressure pattern of chronic constrictive pericarditis was first described by Bloomfield and associates[1] in 1946, and has been subsequently reported by Hansen,[2] Wood,[3] McKusick,[4] Yu,[5] Harvey,[6] and Wilson.[7] These pressure patterns consist of the following: (1) an M or W contour of the right auricular pressure tracing, (2) an early diastolic dip followed by a rapid rise of the right ventricular pressure to form a plateau, (3) a ratio of the right ventricular end diastolic to systolic pressure greater than one-third, and (4) a decrease in the pressure gradient between the right auricle to the pulmonary artery.

This pattern is quite characteristic but not pathognomonic for chronic constrictive pericarditis. Various conditions which hinder the effective ventricular contraction and diastolic relaxation, particularly the latter, may produce a similar pattern. Such conditions are extensive pericardial effusion,[7,8] myocardial fibrosis,[9] primary amyloidosis[10,11] of the heart, various kinds of right heart failure,[7] and subendocardial fibroelastosis.[11]

This study attempts to re-evaluate the mechanism and validity of this pattern and to present two cases of severe constrictive pericarditis. Severe degree of constriction results in an interesting type of right heart pressure pattern. Of seven cases of constrictive pericarditis, six were corrected by pericardiectomy. One case was not proved because of the patient's refusal to permit surgery. The formation of the right auricular pressure pattern has been described by pioneer observers.[2,5,7] However, the detailed mechanism of its formation needs further investigation.

METHOD

The right heart pressure was recorded preoperatively and postoperatively by the usual recognized cardiac catheterization technique by a Sanborn four-channel Poly-viso direct recorder. A reference point for pressure measurements was selected 10 cm. above the level of the back in the supine position. The

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pressure transducers were calibrated with a mercury manometer. Though we did not use the double lumen cardiac catheter to register the simultaneous right auricular and ventricular pressures, the latter pressures were approximated by mounting simultaneous electrocardiograms with the beginning of each cardiac cycle. Therefore sufficiently accurate timing was obtained by this technique.

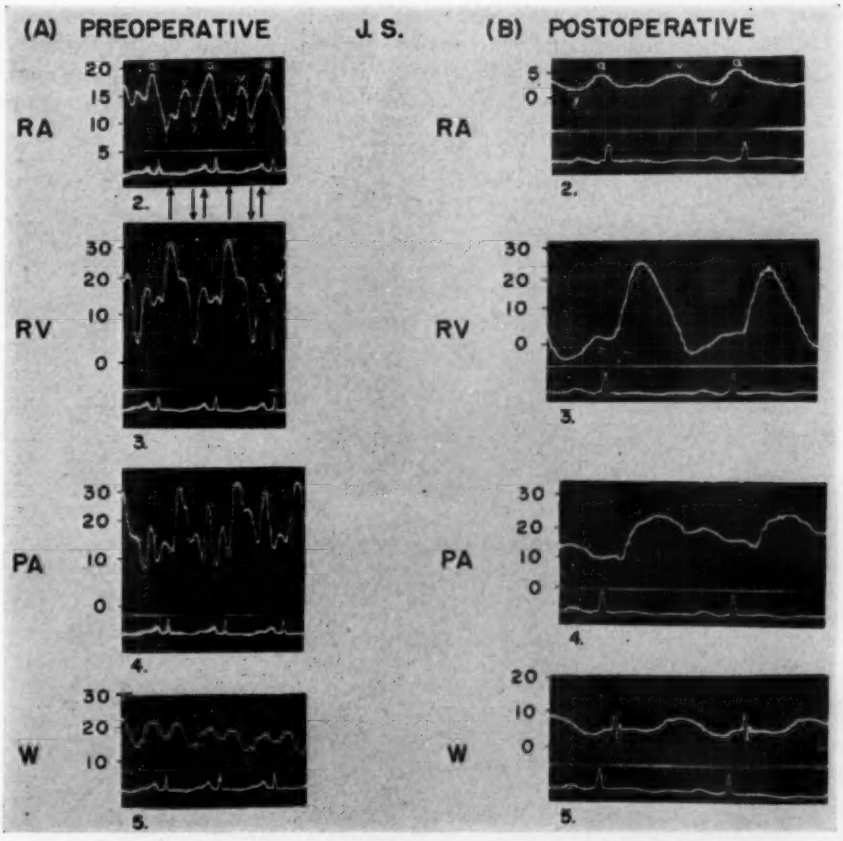

Fig. 1.—A 19-year-old boy shows a dramatic clinical improvement after pericardiectomy. The preoperative pressure tracings were recorded at 25 mm./sec. speed, and the postoperative pressure tracings were recorded at 50 mm./sec. speed. The giant a wave type is presented in (A) preoperative tracing.

RESULT AND DISCUSSION

A. *Right Auricular Pressure Pattern.*—In a normal right auricular pressure tracing there are three positive waves—a, c, and v, as well as three negative waves —x, x′ and y. Any physiologico-pathologic condition which may exaggerate one of these waves may result in M or W pattern of right auricular pulse wave. Usually the x wave is very small and is often fused with the a or the c wave. Therefore the influence of the x wave on the negative auricular waves can usually be neglected. The right auricular pressure pulse patterns are affected by several factors: venous filling pressure, right auricular distensibility, vigor of right auricular systole, auriculoventricular resistance, tricuspid valvular lesion, and

right ventricular status. For convenience and simplicity of discussion we have classified the right auricular pressure tracings into six wave types.

1. *Giant a wave type:* The mechanism of formation of giant a wave in chronic constrictive pericarditis is probably due to the incompleteness of auricular emptying during the rapid inflow period of the right ventricular filling and possible increment of atrioventricular resistance. As a giant a wave occurring with each cardiac cycle, there will be an M or W right auricular pressure pattern formed. It has been proposed by McCord and associates[10] that the significant factor of the genesis of the giant a wave in pure pulmonary stenosis is due to a lesser degree of the distensibility of the hypertrophied right ventricle. In order to compensate for normal right ventricular filling of a hypertrophied right ventricle, the hypertrophy of the right auricle occurs and the increased force of atrial systole is manifested by a giant a wave. Due to the pericardial

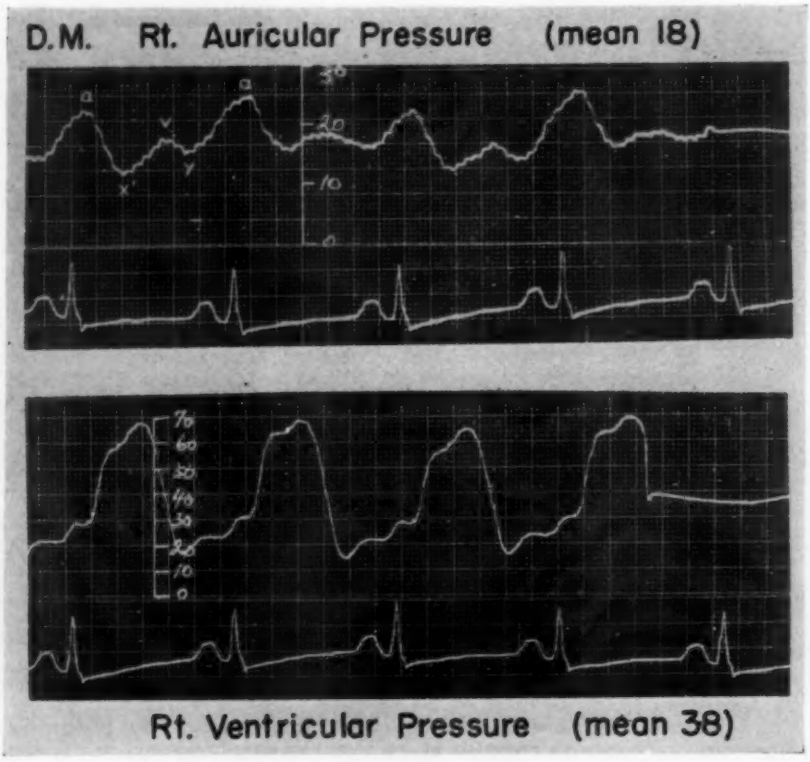

Fig. 2.—A 6-year-old boy with progressive congestive heart failure. Cardiac catheterization studies reveal no shunt. The tracings were recorded at 50 mm./sec. speed. The right heart pressure pattern shows similar pattern as in constrictive pericarditis.

constriction, the right atrioventricular resistance may logically increase as a result of limited right ventricular distensibility. This pattern is well shown in Fig. 1. However, this pattern is also seen in other conditions associated with right ventricular hypertrophy, such as pulmonary stenosis.[12,13] Fig. 2 also demonstrates the giant a wave in the right auricular pressure tracing, simulating an M or W pattern in an undiagnosed case of congestive heart failure. This is a 6-year-old, underdeveloped boy suffering from cardiac decompensation, poor weight gain, and hepatomegaly. The fluoroscopy shows enlargement of both ventricles with normal cardiac pulsation. Electrocardiogram shows prominent P waves, tall R waves, and flat T waves throughout the tracing. The cardiac catheterization demonstrates no evidence of R-L or L-R shunt. Femoral arterial oxygen saturation is normal. Tuberculin skin test is negative. The possibility of subendocardial fibroelastosis is seriously considered. The possibility of constrictive pericarditis is very unlikely because of normal cardiac pulsation and electrocardiographic findings.

2. *Prominent v wave type:* As the v wave becomes the prominent one in the right auricular pressure tracing, an M or W pattern will also be noted. A high venous filling pressure followed by a deep y wave may be the underlying mechanism for the formation of a prominent v wave as shown in Fig. 3. However, this type of atrial tracing is by no means specific for constrictive pericarditis. In Fig. 4, this pattern is shown from a case of ruptured congenital aneurysm of the sinus of Valsalva associated with a small ventricular septal defect, proved by autopsy.

3. *Deep y wave type*[1-5]*:* In most cases of constrictive pericarditis the y wave correlated quite well with the right ventricular diastolic dip. The a and v waves are usually exaggerated and more prominent as a deep y wave is present. By this mechanism the M or W contour becomes rather conspicuous. The deep y wave is well demonstrated in Figs. 1, 3, 5, and 6.

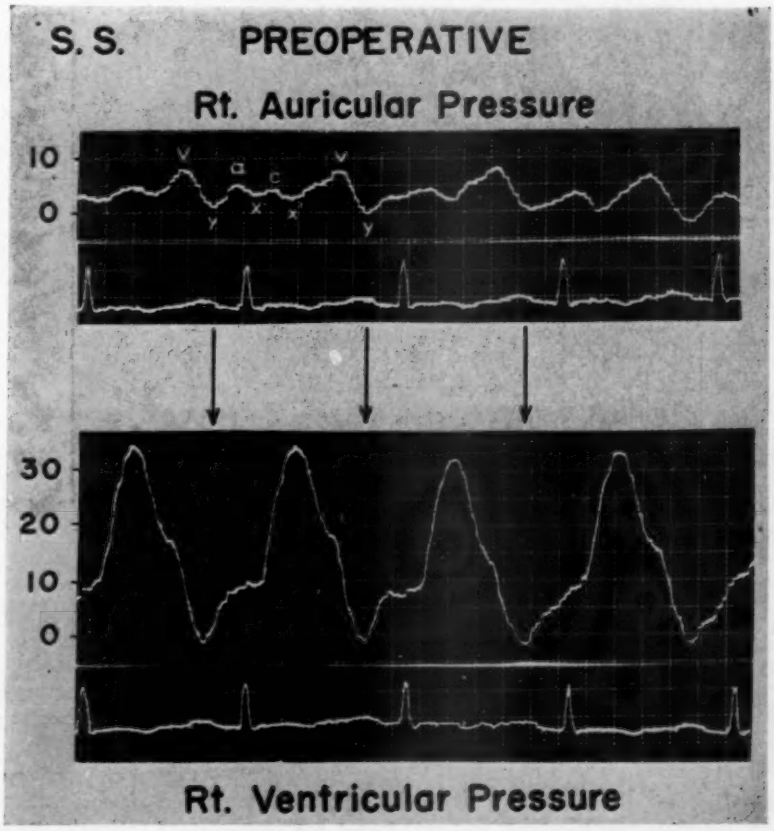

Fig. 3.—A 33-year-old man was admitted with fever, chest pain, cardiac enlargement, and positive tuberculin skin test. Cardiac catheterization studies were compatible with constrictive pericarditis. The tracings were registered at 50 mm./sec. speed.

4. *The s wave type:* The right auricular pressure pattern is greatly distorted when a tricuspid valvular lesion is present. As in the case of tricuspid regurgitation, the right ventricular systolic pressure is well transmitted into the right auricle so that the s wave is produced. The M or W shape usually is not formed while the s wave is present. This demonstrates that the absence of an M or W pattern in the right atrial pulse tracing is not a necessary criterion for diagnosing constrictive pericarditis. The s wave type is well demonstrated in Fig. 6.

5. *Irregular type:* The irregular auricular pattern is encountered in cases of auricular or ventricular arrhythmia. Of course, it will be further disturbed if it is accompanied by a tricuspied lesion. Fig. 7 shows an irregular auricular pattern in a constrictive pericarditis patient with auricular fibrillation, after the first partially successful pericardiectomy. In most cases of con-

strictive pericarditis there is a good time correlation between the diastolic dip and y wave. However, the y wave may be insignificant in a severe case. Occasionally there is a small positive wave in the right auricular tracing before the appearance of the a wave. This may be explained by the fact that a high positive right ventricular wave is formed following the diastolic dip resulting from the limited right ventricle being filled up rapidly after rapid powerful right auricular emptying. This high right ventricular pressure wave produces a transmission into the right auricle through the tricuspid valve. We name this small positive wave c′ wave, as it is clearly shown in Figs. 1 and 6. Of these two cases, we do not believe there was a significant amount of tricuspid regurgitation in the first case, as there were no s waves present.

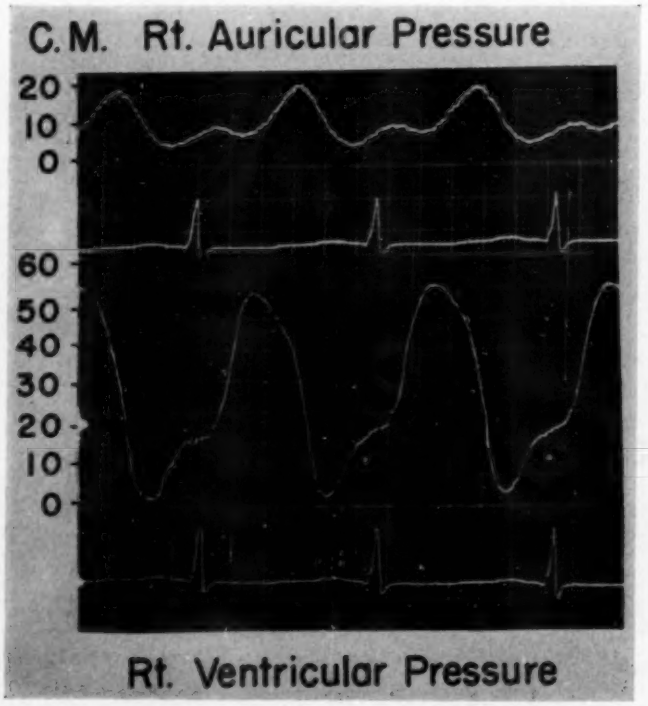

Fig. 4.—A 13-year-old boy, autopsy proved case of ruptured sinus of Valsalva. The right heart pressure pulse curves show W shaped atrial pressure pulse and similar right ventricular pattern as in constrictive pericarditis.

6. *Flat wave type:* In severe constrictive pericarditis there is a marked elevation of the right heart diastolic pressure and x′ and y waves become less conspicuous. Furthermore, there is a broad flat positive wave starting immediately after the peak of P wave and lasting longer than the usual a wave. It is probably due to the fusion of both the a and the c waves. We have no good explanation for the inconspicuous small v wave in this type. This peculiar curve pattern is noted in two severe constrictive pericarditis patients in the present series (Figs. 8 and 9). Both of these two patients had a higher venous pressure than the rest of the cases. Since the y wave depends mainly upon the sudden lowering of the early right ventricular diastolic pressure, the depth of the y wave will be greatly reduced because of the absence of the diastolic dip in severe constrictive pericarditis. Therefore, there is no M or W pattern demonstrated in this type of constrictive pericarditis.

B. *Right Ventricular Pressure Pattern.*—The right ventricular pressure pattern is very characteristic in this entity and is an extremely useful aid for deciding surgical operability. The following discussion attempts to elucidate its mechanism of formation.

1. *Diastolic dip*[1,2,4]*:* The early diastolic dip, usually present, is explained by the fact that the limited right ventricular diastolic volume is filled rapidly due to a powerful high right atrial filling pressure. However, it must be stated that the diastolic dip may be absent or minimal in a severe constriction, as shown in Figs. 8 and 9.

2. *Diastolic oscillation*[7]*:* We are led to believe that the diastolic oscillation which occurs immediately following the diastolic dip is due to the balancing vibrations between the two relatively high pressure chambers, right auricle and ventricle. As it is pointed out by Issacs,[8] a mid-diastolic rumble may occasionally be detected by auscultation.

3. *Diastolic plateau*[2,5]*:* Following the diastolic oscillation during the period of diastolic diastasis, the right auricle and ventricle become a sort of common chamber effect; there is a minimal pressure gradient between the two chambers and a diastolic plateau is formed.

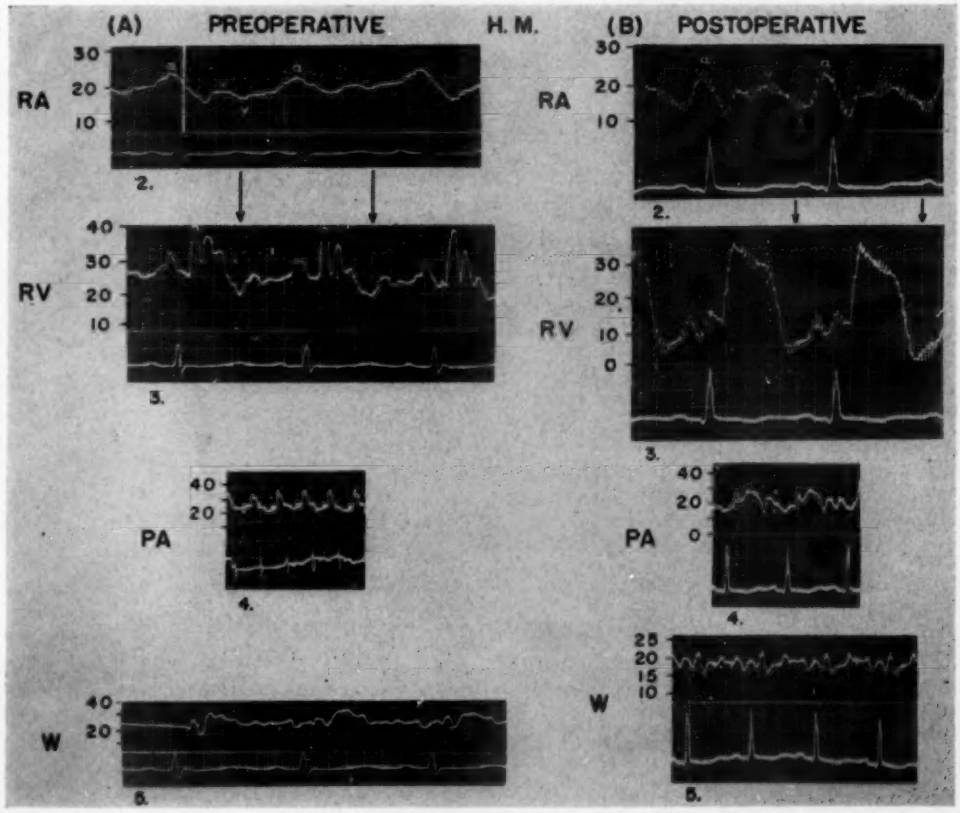

Fig. 5.—A 40-year-old man with constrictive pericarditis shows a dramatic improvement after pericardiectomy. The preoperative record shows marked elevation of right ventricular diastolic pressure with insignificant degree of diastolic dip. The presystolic rise of end right ventricular pressure are rather marked in pre- and postoperative records.

4. *A ratio of the right ventricular end diastolic to systolic pressure greater than one-third*[5]*:* As pointed out by Yu,[5] the right ventricular end diastolic to systolic pressure ratio is more than one-third in constrictive pericarditis, but we think that an additional criterion should be a resting right ventricular systolic pressure of not more than 50 mm. Hg. The relatively low right ventricular systolic pressure in constrictive pericarditis is best interpreted by the generalized constriction of both ventricles. Because of the uniform pericardial involvement, the mechanical ventricular imbalance is minimized. According to Issacs,[8] experimental data show the pericardial involvement of the left ventricle in the presence of an intact right ventricle usually gives rise to more marked pulmonary hypertension. Once the resting right ventricular systolic pressure is greater than 50 mm. Hg, left heart disturbances of other types should be considered.

5. *Presystolic rise of the right ventricular end diastolic pressure:* The normal presystolic rise of the right ventricular end diastolic pressure is exaggerated by a limited right ventricular diastolic capacity. This phenomenon is further accentuated by a giant a wave. It is a compensating mechanism to the incomplete right ventricular filling which is greatly reduced during the rapid inflow period in this entity. In case of auricular fibrillation this rise is not significant. It is demonstrated in two cases of this series, as in Fig. 5 (*A* and *B*), and 8,*A*; however, it is a nonspecific change as shown in Fig. 2, an undiagnosed case of congestive heart failure.

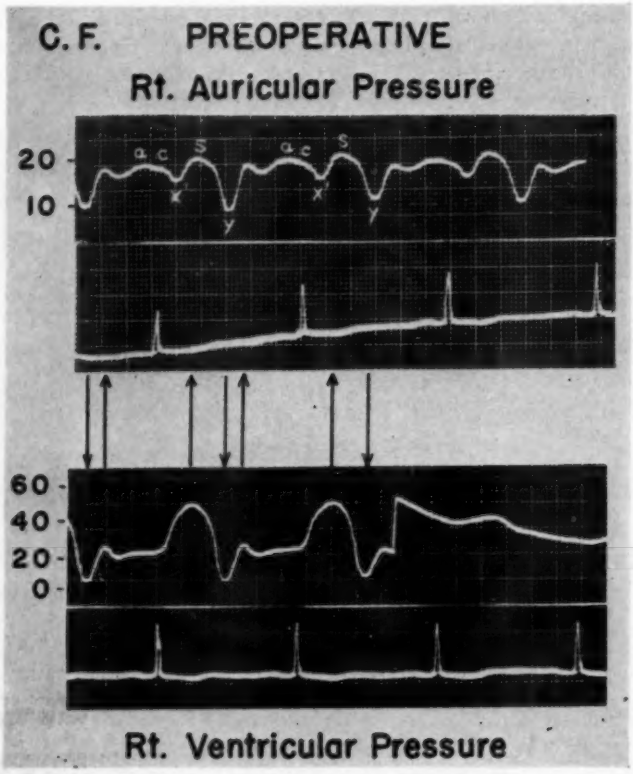

Fig. 6.—A 59-year-old man with constrictive pericarditis and calcification of pericardium shows no clinical improvement after pericardiectomy. The preoperative right heart pressure tracings demonstrated a, c, x′, s, y, and c′ waves.

6. *Flat wave pattern of the right ventricular pressure:* In severe cases the right ventricle reduces the ability to contribute the foreward movement. The initial length and tension have a close relation with cardiac systolic response.[16] There is a reduction of force in both systole and diastole of the right ventricle. Because of severe constriction, there is a slight decrease of the right ventricular systolic pressure instead of the usual rise. Because of severe constriction, the right ventricular diastole is so impaired that the diastolic dip becomes insignificant. In order to maintain the circulation, there is a secondary rise of right atrial and caval pressures. Of course the high pulmonary diastolic pressure is due to the left ventricular involvement.[8,14,15] Therefore, the flat wave pattern in the right heart is produced. There was no evidence of an overdamping effect of the recorder during the procedure. In spite of absence of diastolic dip, a diastolic oscillation, or a diastolic plateau, these patients may still have constrictive pericarditis.

Clinical studies also pointed out that the pulmonary hypertension due to constrictive pericarditis is slight or moderate.[1-3,5-7,9-14] Fig. 2 demonstrates the ratio of the right ventricular end diastolic to systolic pressure greater than one-third with right ventricular systolic pressure being 70 mm. Hg. It happens to be an undiagnosed case of congestive heart failure of a 6-year-old boy.

POSTOPERATIVE CHANGES IN THE RIGHT HEART PRESSURE PATTERN

The comparative preoperative and postoperative changes in the right heart pressures are demonstrated in Table I. Briefly, the postoperative changes in the right heart pressure can be stated as follows:

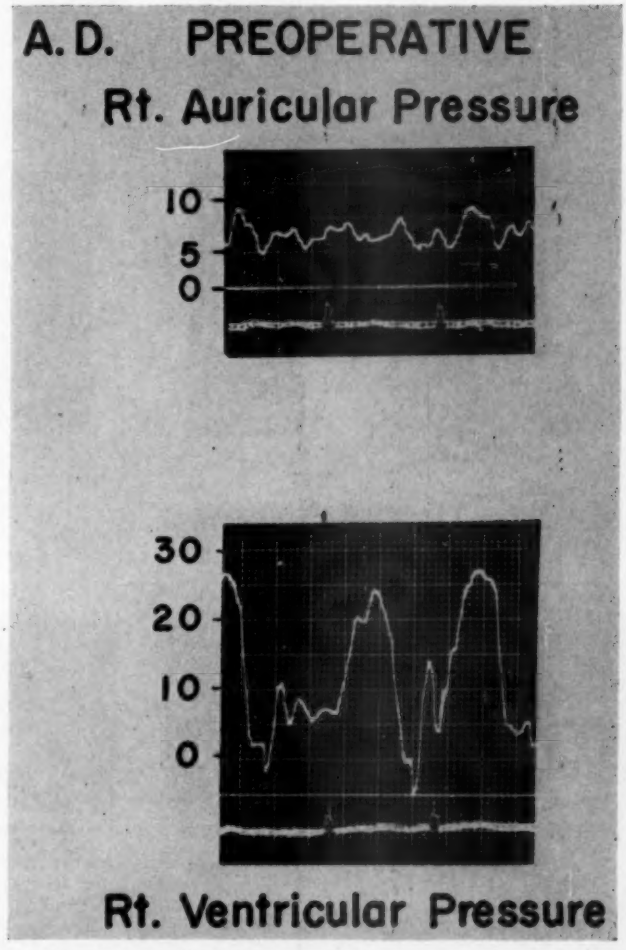

Fig. 7.—A 44-year-old man suffers from constrictive pericarditis and auricular fibrillation. The right atrial and ventricular tracings were taken after first pericardiectomy, showing irregular right atrial pulse pattern.

1. Decrease in mean auricular pressure and normalization of the individual waves of the right auricle are the usual changes after a successful pericardiectomy.

2. In most cases there is a reduction of both systolic and diastolic pressure in the right ventricle and pulmonary artery. However, in severe cases (Figs. 8 and 9) there is a slight rise of the right ventricular and pulmonary systolic pressure postoperatively.

3. Entire normalization of the right heart pressure pattern is unusual. As a rule, there are some residual changes after pericardiectomy. There is no direct correlation between the severity of the pressure pattern and the predictability of the postoperative recovery. The myocardial factor,[6] degree of the constriction, and age of the patient should all be considered. The postoperative evaluation and the possible second pericardiectomy should be judged from the light of the clinical picture rather than the pressure pattern alone.

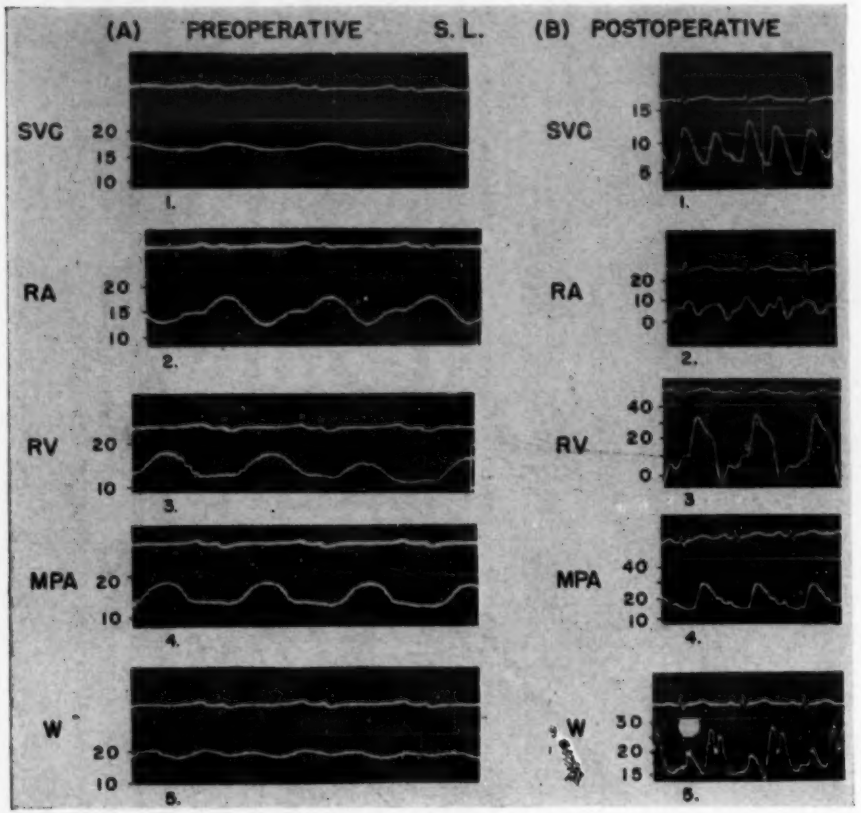

Fig. 8.

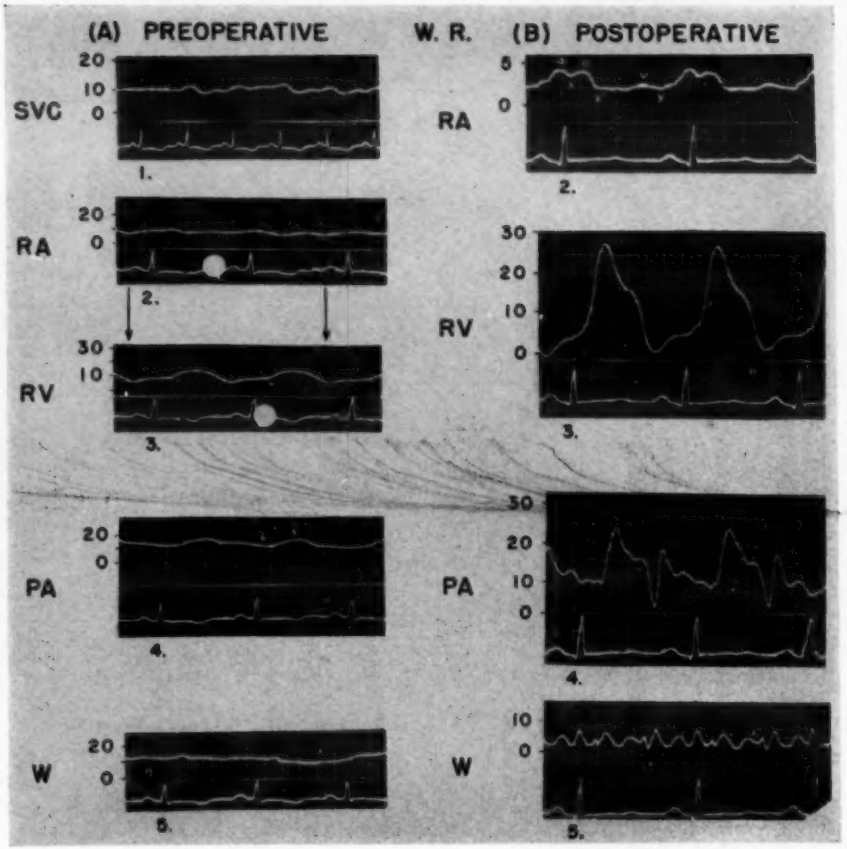

Fig. 9.

Fig. 8.—A 14-year-old girl shows a dramatic improvement after a successful pericardiectomy. The preoperative right heart pressure pattern (at 50 mm./sec. speed) shows a severe constriction, with flat wave type. The postoperative record (at 25 mm./sec. speed) demonstrates marked improvement.

Fig. 9.—A 27-year-old man shows a dramatic improvement after pericardiectomy. The postoperative record of right heart pressure tracing shows disappearance of the flat wave pattern.

TABLE I. RIGHT HEART PRESSURE STUDIES ON CHRONIC CONSTRICTIVE PERICARDITIS

PATIENT'S NAME		SUPERIOR VENA CAVA	RIGHT AURICLE	RIGHT VENTRICLE			PULMONARY ARTERY			PULM. CAP. WEDGE (MEAN)
				SYSTOLIC	DIASTOLIC		SYS.	DIAST.	MEAN	
					EARLY	END				
J.S.	Preop.	12	12	32	4	13	32	10	18	15
	Postop.	4	4	25	− 2	4	25	12	15	5
S.L.	Preop.	17/16	17/12	18	11	11	18	15		19
	Postop.	12/16	10/2	32	− 4	10	30	12	20	?
A.D.	Preop.		9/5	28	− 3	6	28	12		8
	Postop.		6/3	28	0	3	28	15	16	
W.R.	Preop.	10	10	18	6	8	18	12		
	Postop.		2	25	0	5	25	8		5
H.M.	Preop.		24/16	40	20	25	40	25		25
	Postop.		18/8	35	5	15	35	15		15
S.S.	Preop.	8/2	8/2	35	− 2	10				
C.F.	Preop.	19	19	45	0	20				

With our limited experience we feel that the right heart pressure patterns are quite characteristic in constrictive pericarditis but not pathognomonic. Both right auricular and ventricular pressure tracings should always be carefully studied simultaneously in order to gain a better understanding. In combination with the clinical information the right heart pressure patterns are helpful diagnostic tools in constrictive pericarditis.

SUMMARY

1. Detailed discussion of the mechanisms of formation and significance of the right auricular and ventricular pressure patterns are presented.

2. Both the auricular and ventricular pressure patterns are characteristic in constrictive pericarditis, but not pathognomonic.

3. Two cases of severe constrictive pericarditis with an interesting right heart pressure pattern are presented.

4. In combination with the clinical picture, the right heart pressure patterns are important in diagnosis and treatment of pericardial and myocardial diseases.

SUMMARIO IN INTERLINGUA

Es presentate studios de catheterisation cardiac in septe casos de pericarditis constrictive, insimul con un re-evalutation del mechanismo de formation e del signification de configurationes del pression dextero-cardiac. Post revider

studios de pression dextero-cardiac basate super plus que 300 casos de catheterisation cardiac in varie typos de congenite e acquirite morbos, nos conclude que le configurationes del pression dextero-cardiac in pericarditis constrictive es multo characteristic sed non pathognomonic. Es etiam presentate un interessante curva de pression occurrente in sever pericarditis constrictive.

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QUANTITATIVE AND QUALITATIVE CORRELATIONS BETWEEN R AND POSITIVE T WAVES IN THE STANDARD LEADS AND THEIR CLINICAL SIGNIFICANCE

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POSITIVE T waves in Leads I and II are electrocardiographic evidence of the physiologic state of the ventricular musculature and constitute a fundamental element of the normal electrocardiogram. However, positive T waves may present many significant details which increase the informative value of electrocardiographic examination in respect to the ventricular myocardium. Alzamora-Castro and associates[1] have called attention to certain T waves, normal in size and polarity, but abnormal in contour, namely, symmetrical aspect, unusually sharp or blunt peaks, notching, etc., that may represent the only objective evidence of abnormal conditions in the ventricular myocardium.

The normal T wave is asymmetrical with a gradual ascending and a more abruptly descending slope. An imaginary plumb line dropped from the apex forms a larger angle with the ascending than with the descending limb. Positive T waves found in cases of myocardial injuries due to coronary arterial diseases, as stressed especially by Goldberger[2] are often symmetrical. Levine and associates[3] describe the tent-shaped, symmetrically built positive T waves in cases of potassium intoxication as a peculiar manifestation of damaged myocardium. Dressler, Roesler, and Lackner[4] establish the significance of the notched positive T waves both in the standard and in the precordial leads, a sign they consider equivalent to the inversion of this wave which may follow impairment of the coronary blood flow.

In addition to these qualitative changes, the question often arises as to whether the height of a positive T wave is normal, or abnormally low or high. In common electrocardiographic practice this problem is decided empirically by simple estimation, and seldom is the observed height compared with established standard values. Another evaluation of the height of the positive T wave in Lead I has been introduced by Dressler[5] by comparing that with its height in Lead III. T_1 has often been found lower than T_3 in cases of anterior myocardial infarction.

In the present paper, results are reported obtained with a new method employing some as yet nondescribed correlations between the positive T wave and the R wave of the same ventricular complex. The behavior of a straight line, prolonging the descending limb of the T wave and its intersection with the R

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wave was investigated. This graphical analysis permitted the establishment of different types of crossing which have been studied minutely to recognize the nature of the determining factors and their clinical correlations.

METHOD AND MATERIAL

The descending limb of the T wave was prolonged upward by a straight line, called crossing line, so that it either (1) intersects the R wave (direct or real crossing), (2) touches the apex of this wave (touching), (3) intersects, above R, the prolongation of the perpendicular line which passes through the apex of the R wave (imaginary crossing or no crossing) (Fig. 1). The distance from the point of intersection to the isoelectric line is denominated crossing height and it is measured in millimeters. In cases of touching, crossing height equals the

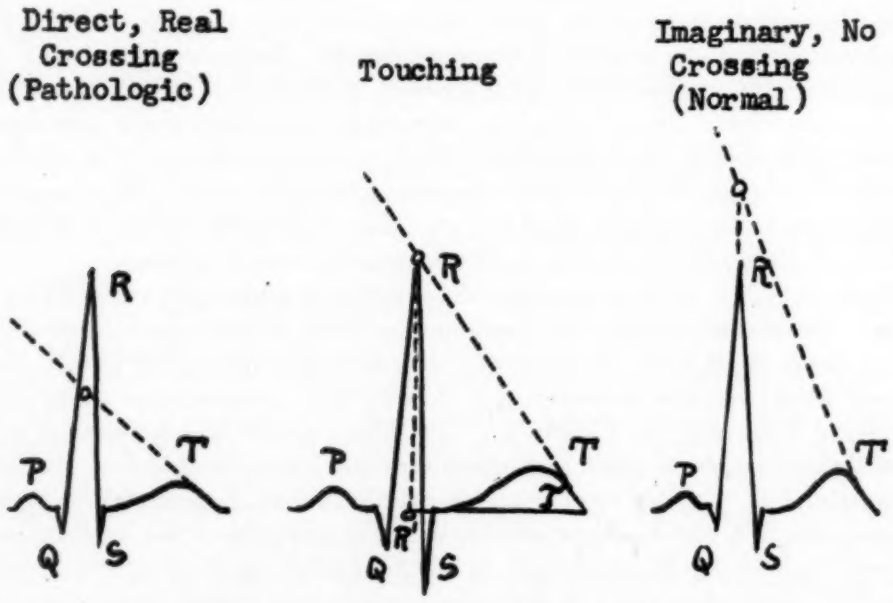

Fig. 1.—The three crossing patterns between R and positive T waves.

height of the R wave. In any other two cases, crossing differences arise. In case of real crossing the peak of the R wave lies above the crossing line and thus to obtain the corresponding crossing height, crossing distance, i.e., the interval between the peak of the R wave and the crossing point, must be subtracted from the height of the R wave. In contrast, in cases of imaginary crossing, crossing distance must be added to the height of the R wave. In cases of real crossing, crossing distance is negative and in those of imaginary crossing it is positive.

As a special feature of the present investigation, the degree of elevation of the descending limb of the T wave was determined by means of the angle τ which is formed by the descending limb of the T wave and the isoelectric line. It is calculated as follows: When the peak of the R wave is projected on the iso-

electric line and the crossing line has been drawn, a rectangular triangle is formed whose hypotenuse is the crossing line, its vertical cathetus is the crossing height, and its horizontal cathetus is represented by that part of the isoelectric line which extends from the projection of the peak of the R wave to the end of the T wave. This distance, which is a part of the Q-T interval, will be designated as R′-T interval. From the graphical representation (Fig. 1) it is apparent that

$$\tan \tau = \frac{\text{crossing height}}{\text{R′-T}}$$

and from this equation the numerical value of the angle τ can be determined by logarithmic calculation. Because crossing height is expressed in millimeters, duration of the R′-T interval must be transformed in millimeter measure also. This can be easily performed by dividing the duration of the R′-T interval, expressed in hundredths of a second, by the speed of the electrocardiographic apparatus employed. In the present study a Sanborn instomatic electrocardiograph was used which registers, as do most similar apparatus, with a speed of 1 mm./0.04 sec., therefore the length of the R′-T interval expressed in millimeters = duration in 0.01 sec./4.

In every record the height of the R and T waves, and the duration of R-R and R′-T intervals were measured. The exact position of the crossing point in relation with the R wave was determined by a rule. Angle τ was calculated as described above. In cases where correlation between the angle τ and the position of the electrical axis was studied, the formula of White and Bock[6] and the chart devised by Carter and associates[7] were applied. The average values were calculated in every group for a more precise evaluation of compared data. All measurements were made in standard Leads I and II.

Observations were made in a group of one hundred healthy men and women, chosen at random. To correlate the angle τ with the cardiac rate, normal records were divided into groups with frequencies ranging from 51 to 120 beats per minute. Each group comprised twenty observations. Furthermore, twenty hypertensive and twenty cardiac patients exhibiting abnormal positive T waves in Leads I and II of varying etiology were studied separately.

RESULTS

Healthy Subjects.—

In one hundred healthy individuals, chosen at random, the measurements gave the results shown in Table I:

Age.—The average age was 40 years, with a range from 17 to 64 years.

Cardiac Rate.—Average was 78 beats per minute, with a range from 54 to 110. Extreme values were observed only exceptionally.

Lead I.—

R wave: Average height was 6.07 mm., with a range from 1.0 to 14.0 mm.

T wave: Measured height averaged 2.23 mm., with a range from 1.0 to 5.0 mm.

R/T ratio: Calculated average amounted to 2.78, with a range from 0.75 to 9.0

Crossing: The crossing line passed above the peak of the R wave in 93 of the cases. In the remaining 7 cases it was tangent to the peak. Thus, in 100 healthy subjects, not a single direct crossing was observed.

Crossing distance: The average distance measured 4.75 mm. with a standard deviation of ±3.15 and with a range from 0 to 16.0 mm.

Crossing height: The average observed height was 10.8 mm., with a range from 5.0 to 24.5 mm.

Angle τ: Its average magnitude was 50°49′, with a range from 28°31′ to 83°7′.

Lead II.—

R wave: The average measured height was 6.97 mm., with a range from 1.0 to 20.0 mm.

T wave: Its height averaged 2.66 mm., with a range from 1.0 to 6.5 mm.

R/T ratio: Average calculated ratio was 2.73, with a range from 0.28 to 18.0.

Crossing: In the overwhelming majority, 90 instances, real crossing was absent; touching occurred in 4, and real crossing was observed only in 6 instances.

Crossing distance: The average distance measured 5.84 mm., with a standard deviation of ± 4.5 and with a range from −9.0 to 17.0 mm.

Crossing height: It measured 12.82 mm. on an average, with a range from 5.0 to 28.5 mm.

Angle τ: Its average value amounted to 54°55′ with a range from 26°41′ to 73°7′.

TABLE I. ONE HUNDRED HEALTHY SUBJECTS

	AVERAGE	RANGE	LEAD I		LEAD II	
			AVERAGE	RANGE	AVERAGE	RANGE
Age (Yr.)	40	17–64				
Rate (Min.)	78	54–110				
R (MM.)			6.07	1.0 –14.0	6.97	1.0 –20.0
T (MM.)			2.23	1.0 – 5.0	2.66	1.0 – 6.5
R/T			2.78	0.75– 9.0	2.73	0.28–18.0
Crossing Distance (MM.)			4.75 ± 3.15	0 + 16.0	5.84 ± 4.5	−9.0 + 17.0
Crossing Height (MM.)			10.8	5.0–24.5	12.82	5.0–28.5
Angle τ (Degree)			50°49′	28°31′–83°7′	54°55′	26°41′–73°7′
Real Crossing (%)			0		6	
No Crossing (%)			93		90	
Touching (%)			7		4	

Correlations of the Crossing to the Position of the Electrical Axis.—

One hundred normal records were divided into groups according to the position of the electrical axis in the left, right, and no axis deviation, each containing thirty-three observations (Table II).

Left Axis Deviation.—Position of the electrical axis averaged −15°3′, with a range from −1.0° to −41.0°. The White and Bock formula indicated an average position of +14.94 with a range from +4.5 to +28.0.

Lead I.—The R wave presented an average height of 9.24 mm. with a range from 4.0 to 14.0 mm. T wave measured 2.5 mm. in height on an average, with a range from 1.0 to 4.5 mm. R/T ratio amounted to 3.99 on an average, with a range from 1.55 to 9.0. Different types of crossing were observed, as follows: real crossing was absent, touching was observed in 21.2 instances, and imaginary crossing in 78.8. Average crossing distance measured 3.06 mm., with a standard deviation of ±2.81 and with a range from 0 to 11.0 mm. Crossing height averaged 12.3 mm., with a range from 7.0 to 18.5 mm. Finally, angle τ averaged 53°39′, ranging from 39°26′ to 83°7′.

Lead II.—The average height of the R wave was much decreased, 4.09 mm. with a range from 1.0 to 9.5 mm., and the T wave averaged 2.33 mm., with a range from 1.0 to 3.5 mm. R/T ratio was definitely decreased, its average value 2.06 with a range from 0.4 to 4.75. The crossing pattern observed was in 96.9 per cent of the "imaginary" type, whereas touching was found in only one case, 3.1 per cent. Real crossing was absent. The average crossing distance measured 6.5 mm. with a standard deviation of ±3.3 and with a range from 0. to 13.0 mm. The crossing height averaged 10.59 mm. with a range from 5.0 to 17.0 mm. Angle τ presented a magnitude of 49°28′ on an average, with a range from 26°41′ to 62°19′.

TABLE II. CORRELATIONS OF THE CROSSING TO THE POSITION OF THE ELECTRICAL AXIS

	AVERAGE	RANGE	LEAD I		LEAD II	
			AVERAGE	RANGE	AVERAGE	RANGE
Left Axis Deviation						
Angle α	−15.3°	−1.0°–41.0°				
Wh. and B. formula	+14.94	+4.5+ 28.0				
R (MM.)			9.24	4.0–14.0	4.09	1.0–9.5
T (MM.)			2.5	1.0–4.5	2.23	1.0–3.5
R/T			3.99	1.55–9.0	2.06	0.4–4.75
Crossing distance (MM.)			3.06± 2.81	0–11.0	6.5± 3.3	0–13.0
Crossing height (MM.)			12.3	7.0–18.5	10.59	5.0–17.0
Angle τ			53°39′	39°26′–83°7′	49°28′	26°41′–62°19′
Real crossing (%)			0		0	
No crossing (%)			78.8		96.9	
Touching (%)			21.2		3.1	
No Axis Deviation						
Angle α	+49.5°	+3.0°+90.0°				
Wh. and B. formula	1.85	−12.5+16.0				
R (MM.)			5.9	2.0–13.0	8.15	3.0–19.0
T (MM.)			2.1	1.0– 5.0	2.79	1.0– 5.0
R/T			2.77	1.2– 4.5	2.86	1.2–18.0
Crossing distance (MM.)			4.85± 3.11	1.0–16.0	5.35±4.2	−3.0–15.0
Crossing height (MM.)			10.75	5.0–24.5	13.50	6.0–23.5
Angle τ			50°10′	35°32′–69°25′	56°24′	33°56′–67°51′
Real crossing (%)			0		5.9	
No crossing (%)			100		91.1	
Touching (%)			0		3.0	
Right Axis Deviation						
Angle α	108°	93°–170°				
Wh. and B. formula	−8.03	−2.0–20.0				
R (MM.)			3.09	1.0– 8.0	8.04	1.0–20.0
T (MM.)			2.09	1.0– 5.0	2.94	1.0– 6.5
R/T			1.6	0.75–5.0	3.27	0.28–10.0
Crossing distance (MM.)			6.33± 2.53	3.0–12.0	5.71±5.7	−9.0–17.0
Crossing height (MM.)			9.42	5.0–19.0	13.75	8.0–28.5
Angle τ			48°73′	28°31′–67°10′	58°53′	39°36′–73°7′
Real Crossing (%)			0		12.2	
No Crossing (%)			100		81.8	
Touching (%)			0		6.0	

No Electrical Axis Deviation.—Average position of the electrical axis expressed in terms of degrees of an angle was +49°5′, with a range from +3.0° to +90.0°, whereas the formula of White and Bock indicated an average value of +1.85 with a range from −12.5 to +16.0.

Lead I.—The average height of the R wave measured 5.9 mm., with a range from 2.0 to 13.0 mm. The T wave presented an average height of 2.1 mm., with a range from 1.0 to 5.0 mm. The R/T ratio was 2.77, with a range from 1.2 to 4.5. Crossing was of "imaginary" type in 100 per cent of the cases. The crossing distance averaged 4.85 mm., with standard deviation of ±3.11 and with a range from 1.0 to 16.0 mm. Crossing height averaged 10.75 mm. with a range from 5.0 to 24.5 mm. Angle τ measured 50°10′, with a range from 35°32′ to 69°25′.

Lead II.—The height of the R wave was 8.15 mm. on average, with a range from 3.0 to 19.0 mm. The T wave averaged 2.79 mm., with a range from 1.0 to 5.0 mm. The R/T ratio amounted to 2.86 on average, with a range from 1.2 to 18.0. Crossing occurred in 91.1 per cent according to the imaginary type, touching was present in 3.0 per cent, and real crossing could be observed in 5.9 per cent of the cases. Average crossing distance measured 5.35 mm., with standard deviation of ±4.2 and with a range from −3.0 to +15.0 mm. Crossing height averaged 13.5 mm., with a range from 6.0 to 23.5 mm. Angle τ measured 56°24′ on an average, with a range from 33°56′ to 67°51′.

Right Axis Deviation.—Position of the electrical axis was +108° on an average, with a range from +93° to +170°. The White and Bock formula indicated an average value of −8.03, with a range from −2.0 to −20.0.

Lead I.—The average height of the R wave was the smallest found among the examined positions: 3.09 mm. with a range from 1.0 to 8.0 mm. The T wave presented an average height of 2.09 mm., with a range 1.0 to 5.0 mm. R/T ratio was 1.6 on an average, with a range from 0.75 to 5.0. Crossing was of imaginary type in every instance. Crossing distance was 6.33 mm., with standard deviation of ±2.53 and with a range from 3.0 to 12.0 mm. Average crossing height measured 9.42 mm., with a range from 5.0 to 19.0 mm. Angle τ was 48°37′ on an average, with a range from 28°31′ to 67°10′.

Lead II.—R wave presented an average height of 8.04 mm., with a range from 1.0 to 20.0 mm. T wave reached its greatest height measuring 2.94 mm. on an average, with a range from 1.0 to 6.5 mm. R/T ratio was 3.27 on an average, with a range from 0.28 to 10.0. Imaginary crossing occurred in 81.8 per cent, touching in 6 per cent, and real crossing in 12.2 per cent of the cases. The average crossing distance measured 5.71 mm., with standard deviation of ±5.7 and with a range from −9.0 to +17.0 mm. The crossing height averaged 13.75 mm., with a range from 8.0 to 28.5 mm. Angle τ presented its greatest average value of 58°53′, with a range from 39°36′ to 73°7′.

Correlation of the Crossing to the Cardiac Rates (Table III).—

Lead I.—The R wave presented no consistent correlations to the cardiac rates; its height was practically the same, 7.7 mm., at the lowest and highest cardiac frequencies. In contrast, the T wave showed a definite and inverse correlation to the cardiac rate. The height of the T wave decreased with increasing cardiac rates. This fact is easily demonstrated by the measurements reproduced in Table III. The average height of the T wave in the group with lowest cardiac rates, from 51 to 60, measured 3.17 mm. and gradually decreased to its minimum value of 1.7 mm. in the group with highest cardiac rates, from 111 to 120 beats per minute. Considering the maximum average height of the T wave at lowest cardiac frequency as 100 per cent, then relative decrease of the T wave from its highest to its lowest value at the highest cardiac rates represents 46.4 per cent. The R/T ratio showed a tendency, not a strict correlation, toward the cardiac rate. Its value increased with increasing cardiac rates. The average ratio measured 2.62 at the lowest cardiac rates, and 5.62 at the highest, thus representing a relative increase of 114 per cent. The crossing phenomena showed definite correlations with the cardiac rates. At low cardiac rates, 51 to 80 per minute, no real crossing was observed; the crossing line always passed above the tip of the R wave. With rates of 81 to 90, real crossing occurred in only one case, 5 per cent. At cardiac rates from 91 to 120 per minute, real crossing occurred with nearly the same frequency, 25, 25, and 20 per cent, respectively. Furthermore, it appeared that the

TABLE III. CORRELATIONS OF THE CROSSING TO THE CARDIAC RATES

CARDIAC RATE (MIN.)	R-R (SEC.)	R'-T (SEC.)	R (MM.)	T (MM.)	R/T	CROSSING DISTANCE (MM.)	CROSSING HEIGHT (MM.)	ANGLE τ (DEGREE)	INCIDENCE OF CROSSING (%)
Lead I									
51–60	1.05	.362	7.77	3.17	2.62	8.5	16.50	62°28′	Real 0 No 100 Touch. 0
61–70	0.90	.344	9.05	2.82	3.5	7.15	16.20	62°3′	Real 0 No 100 Touch. 0
71–80	0.80	.327	7.37	2.37	3.16	4.95	12.32	56°18′	Real 0 No 100 Touch. 0
81–90	0.70	.310	6.70	2.10	3.49	4.37	11.12	55°8′	Real 5 No 95 Touch. 0
91–100	0.63	.290	7.67	1.82	4.51	2.0	9.67	53°8′	Real 25 No 75 Touch. 0
101–110	0.57	.280	7.95	1.75	5.08	1.25	9.20	52°44′	Real 25 No 75 Touch. 0
111–120	0.43	.280	7.67	1.70	5.62	1.07	8.75	51°20′	Real 20 No 70 Touch. 10
Lead II									
51–60			10.75	4.07	2.67	10.5	21.25	67°3′	Real 0 No 100 Touch. 0
61–70			11.37	3.42	3.68	6.17	17.55	63°54′	Real 5 No 95 Touch. 0
71–80			10.35	3.12	3.71	5.67	16.32	63°19′	Real 15 No 75 Touch. 10
81–90			8.27	2.6	3.44	5.22	13.50	60°8′	Real 5 No 95 Touch. 0
91–100			8.52	2.27	4.32	3.95	12.47	59°50′	Real 5 No 80 Touch. 15
101–110			8.10	1.95	4.04	1.82	9.92	54°48′	Real 30 No 65 Touch. 5
111–120			7.52	1.92	4.30	—0.05	9.35	53°11′	Real 30 No 55 Touch. 15

crossing distance was inversely proportional to the cardiac rate. Thus, the average crossing distance in the group with cardiac frequencies from 51 to 60 was 8.5 mm. and it decreased progressively with increasing cardiac rate, reaching its minimum expression, 1.07 mm., in the group with the highest cardiac rate.

The crossing height had inverse correlation with the cardiac rates. Its highest average value, 16.5 mm., was observed in the group with lowest cardiac rates (51 to 60 beats); its values decreased gradually with increasing cardiac rates and reached its lowest value, 8.75 mm., in the group with highest cardiac frequency (111 to 120).

Angle τ presents an inverse correlation with cardiac rate. Its highest average value, 62°28′, was found in the group with lowest cardiac frequency (51 to 60). The magnitude of the angle τ decreased gradually when cardiac rates increased. The lowest average value, 51°20′, was found in the group with the highest cardiac rates (111 to 120 per minute).

Lead II.—The R wave presented its highest average values at low, and its lowest averages at high cardiac rates. Thus, in the group with cardiac rates from 51 to 60, the R wave measured 10.75 mm. and in the group with rates from 111 to 120, 7.52 mm. T wave behaved exactly as described in Lead I. Its height is inversely proportional to the cardiac rate. Its highest average value of 4.07 mm. was found in the group with the lowest cardiac rates (51 to 60) and its smallest value, 1.92 mm., in the most rapid cases (111 to 120 beats). The relative decrease of the height of the T wave, caused by changes in the cardiac frequency from its highest to its lowest value, amounted to 52.9 per cent. The ratio R/T tended to parallel the cardiac rates. Its lowest average value, 2.67, was found in the group with lowest cardiac rates (51 to 60) and its highest value, 4.3, at highest cardiac rates (111 to 120). Real crossing was absent at low cardiac rates. From 61 to 100 in the normal range of cardiac frequencies, crossing was observed with practically equal incidence, namely, 5 per cent, whereas at high cardiac rates from 101 to 120 the incidence of the crossing was 30 per cent. Crossing distance presented a definite indirect correlation with the cardiac rates: its greatest average value of 10.5 mm. was found in the group with lowest cardiac rates; its magnitude decreased with increasing cardiac rates and, finally, its minimum value, −0.05 mm., was observed in the group with highest cardiac frequencies (111 to 120). Crossing height showed identical indirect correlation with the cardiac rates. Its maximum average value of 21.25 mm. was observed at cardiac rates 51 to 60, and it decreased gradually with increasing cardiac rates, reaching its minimum expression of 9.35 mm. at cardiac rates of 111 to 120. Angle τ showed, in a very clear manner already expressed, inverse correlation with the cardiac rates. Its average magnitude in the group with 51 to 60 beats per minute was 67°3′; it decreased gradually when cardiac rates increased, and its minimum average of 53°11′ was observed in the group with highest cardiac frequencies (111 to 120 per minute).

CLINICAL APPLICATION

Cardiac Patients With Hypertension.—Twenty cardiac patients with hypertension were selected. All exhibited the electrocardiographic patterns of the initial stages of left ventricular strain with increased voltage of the R wave and flattened, but still positive, T wave in Lead I. Crossing phenomena could be clearly observed in this group and details of pathologic crossing could be accurately established.

Age.—The average age was 55.7 years with a range from 38 to 77 years.

Blood pressure.—It averaged 179/100 mm. Hg with a range from 160 to 220 mm. Hg systolic and from 80 to 120 mm. Hg diastolic pressure.

Position of the electrical axis.—The average position of the angle α was +4°6′, ranging from +63° to −66°. The White and Bock formula indicated an average value of +17.45, with a range from −0.5 to +32.0. The author's strain index[8] showed an average value of +13.7 with a range from −1.5 to +33.0.

Lead I.—

R wave averaged 12.6 mm., with a range from 8.0 to 17.5 mm.

T wave was 0.8 mm. in height on an average, with a range from 0.5 to 1.5 mm.

R/T ratio measured 19.64 on an average, with range from 5.7 to 37.0.

Crossing occurred in every case, according to the real (direct) type. Crossing distance was always negative, measuring −8.62 mm. on an average, with a range from −2.0 to −17.0 mm. The crossing height averaged 3.97 mm., with a range from 0.5 to 7.0 mm.

Angle τ measured 22°44′ on average, with range from 2°18′ to 36°23′, only 44.4 per cent of the normal average of 50°49′.

Lead II.—

R wave measured 8.02 mm. on an average, with a range from 1.0 to 15.0 mm.

T wave presented an average height of 1.3 mm., with a range from 0.5 to 4.0 mm.

R/T ratio amounted to 8.64 on an average, with a range from 1.0 to 30.0. Direct crossing was observed in 75 per cent and imaginary crossing in 25 per cent of the cases. The average crossing distance measured −1.65 mm., with a range from −12.0 to +12.0 mm. The crossing height averaged 6.37 mm., with a range from 1.0 to 16.0 mm.

Angle τ was markedly diminished; its average value was 30°51′, representing 55.9 per cent of the average standard. The observed range was from 6°49′ to 59°18′.

Miscellaneous Cases.—Twenty patients with various cardiac lesions, but presenting as a main feature an abnormally low positive T wave in Lead I and eventually in Lead II also, were included in this group. Most of them were coronary patients with angina pectoris or patients with heart failure.

Age.—Average was 54 years, ranging from 34 to 78 years.

Lead I.—

R wave average height was 8.1 mm., with range from 4.0 to 17.5 mm.

T wave was flattened; average height of 0.43 mm., with a range from 0.2 to 1.0 mm.

R/T ratio was markedly increased, amounting to an average of 22.6, with range from 8.0 to 52.0.

Crossing of the direct type was observed in every instance. The crossing distance averaged −5.05 mm., with a range from −2.0 to −14.0 mm. The crossing height measured 3.15 mm. on an average, with a range from 1.5 to 6.0 mm.

Angle τ measured 18°31′ on an average, with a range from 10°1′ to 35°13′.

Lead II.—

R wave average height was 6.0 mm., with a range from 1.0 to 10.0 mm.

T wave average height was 1.13 mm., with a range from 0.2 to 3.0 mm.

R/T ratio average was 8.97 with a range from 1.2 to 30.0.

Crossing of different types was observed in this group of patients. Direct crossing was present in 55 per cent, imaginary crossing in 40 per cent, and touching in 5 per cent (1 case). The crossing distance averaged +1.0 mm., with a range from −7.0 to +8.0 mm. The crossing height measured 6.57 mm. on an average, with a range from 1.0 to 15.0 mm.

Angle τ was 32°28′ on an average, with a range from 5°42′ to 61°56′.

DISCUSSION

Changes in the voltage and direction of the T wave in Lead I is of great practical significance to the clinician. All pathologic processes that invert the T wave necessarily produce, in their early stages, a decrease of its positivity. This may occur very slowly in some cases, such as hypertension, or very rapidly, as in cases of anterior myocardial infarction. All these changes occur more frequently and earlier in Lead I than in Lead II. The diagnostic importance of Lead I has been recognized by different investigators for many years. How-

ever, these characteristic changes caused by anterior infarction may appear late, or not at all, a drawback of Lead I that Wolferth and Wood[9] have obviated by introducing the anteroposterior thoracic lead and Whitten[10] the midaxillary lead. Furthermore, the practical importance of Lead I for diagnostic purposes is apparent from conclusions of Dawber, Kannel, Love, and Streeper,[11] who employed Lead I for the detection of heart disease as a screening method, instead of the 12-lead electrocardiogram, solely, and have obtained with both methods practically identical results. Therefore, any additional information concerning the behavior and significance of positive T wave in Lead I and II may be of interest.

As already mentioned, positivity of the T wave is appreciated in common electrocardiographic practice by simple estimation and only seldom by comparison with established standard values (Kossmann[12]). In the present study a new graphical criterion is introduced: the crossing phenomenon between R and positive T waves, which increases our knowledge in relation to the significance of the positive T wave. According to experience, normal crossing pattern is of imaginary type, where no direct crossing occurs between crossing line and R wave. Direct crossing characterizes the abnormal pattern of crossing. Touching is a borderline situation; it can be found in both cases and has no definite significance.

In one hundred normal cases direct crossing was absent in 93 per cent in Lead I, and touching was present in 7 per cent. In Lead II the situation was similar; real crossing was absent in 90 per cent and touching was observed in 4 per cent, whereas real crossing occurred in 6 per cent. The crossing distance measured, in Lead I, 4.75 ± 3.15 mm., with a range from 0 to 16.0 mm. In Lead II it was 5.84 mm. ± 4.5 mm., with a range from −9.0 to +17.0 mm. Crossing height measured, in Lead I, 10.82 mm. on an average, with a range from 5.0 to 24.5 mm., and 12.82 mm., with a range from 5.0 to 28.5 mm., in Lead II. Absolute value of the crossing height depends mainly on the degree of elevation of the descending limb of the T wave expressed by the angle τ and only secondarily on the length of the R′-T interval.

Angle τ measures the degree of elevation of the descending limb of the T wave and is determined by the crossing and the isoelectric lines. Although angle τ does not measure directly the height of the T wave, however, it is so closely related that both expressions, i.e. angle τ in degrees and height of the T wave, refer interchangeably to the size of this wave. Its exact determination can easily be performed trigonometrically because the two catheti represented by the crossing height and the R′-T distance constitute the tangent of the angle τ. In one hundred normal records angle τ averaged in Lead I, 50°49′, with a range from 28°31′ to 83°7′, whereas its corresponding values in Lead II measured 54°55′ and 26°41′ to 73°7′, respectively. These figures indicate that the degree of elevation of the descending limb of the T wave in Lead II is greater than in Lead I, or that T_2 is taller than T_1, a conclusion whose validity has been demonstrated with corresponding data of direct measurements.

Crossing occurs more likely when angle τ is small, R wave is large, and R′-T interval is short. Thus, crossing is directly proportional to the height of the R wave and inversely to the magnitude of the angle τ and the length of the R′-T interval.

The chief factor determining crossing is the width of the angle τ or, in other words, the degree of positivity of the T wave. A special study was carried out to establish quantitatively the correlation of the incidence of the crossing at different magnitudes of the angle τ. A total of 366 measured values of angle τ, corresponding both to normal and abnormal tracings, were classed into groups, each increasing 5 degrees, from 20 degrees to 80 degrees (Table IV). In each group the incidence of real crossing was determined and expressed as a percentage of the corresponding number of observations. The result was conclusive. In cases with an angle τ less than 25 degrees, crossing was observed in every instance. On the other hand, when the angle τ was greater than 60 degrees, no crossing was observed in any case. In the intermediate zone, from 25 degrees to 60 degrees, the incidence of crossing decreased gradually with the successive increase of the angle τ from 80 per cent to 8 per cent, respectively.

TABLE IV. CORRELATIONS OF THE CROSSING TO THE ANGLE τ

ANGLE τ (DEGREES)	NO. OF CASES	CROSSING			
		+	0	+	0
		(NO.)		(%)	
<20	30	30	0	100	0
21–25	13	13	0	100	0
26–30	10	8	2	80	20
31–35	17	13	4	70	30
36–40	38	23	15	60	40
41–45	37	10	27	27	73
46–50	28	4	24	14	86
51–55	75	5	70	7	93
56–60	39	3	36	8	92
61–65	46	0	46	0	100
66–70	21	0	21	0	100
71–75	10	0	10	0	100
76–80	2	0	2	0	100

The ratio R/T, already employed by Einthoven[13] for the study of the influence of respiration on the ventricular complex, was examined in connection with crossing. A correlation was found to exist between the incidence of the crossing and the R/T quotient. No crossing was observed with a ratio under 5.0. With ratios over 8.0, crossing occurred in each case. In the intermediate zone, from 5.0 to 8.0, crossing appeared at random. Observations of the R/T ratio in respect to the crossing phenomenon lend support to the conclusions reached by the study of the angle τ, i.e., that the incidence of crossing is directly proportional to the height of the R wave and inversely proportional to that of the T wave.

A definite correlation exists between the crossing phenomenon and the cardiac rates. No real crossing occurs in normal cases, so long as the cardiac rate is less than 80 per minute. With higher frequencies (90 per minute or more) real crossing will be present in 20 to 30 per cent of normal tracings. This is

caused chiefly by the progressive lowering of the T wave with increasing cardiac rates, whereas the height of the R wave remains practically unchanged in Lead I, and decreases only moderately in Lead II. Thus, the study of the crossing phenomenon adds a new electrocardiographic sign to the interpretation of the tachycardias which, in higher degrees, impair cardiac function. This is expressed by the appearance of pathologic type of crossing.

Whereas change in the cardiac rate influences crossing by modifying the height of the T wave, the influence of the position of the electrical axis is expressed in alterations of the R wave. In Lead I the R wave was tallest in the group with left axis deviation and smallest in that with normal position and with right axis deviation. In opposition to the marked changes in the height of the R wave caused by deviation of the electrical axis, corresponding changes of the T wave were very moderate. In Lead II changes were quantitatively similar but oppositely directed. The highest R wave was found in cases of right and no axis deviation, and lowest in left axis deviation. The corresponding pronounced changes in the value of the R/T ratio were caused mainly by variations in the height of the R wave. Thus, the incidence of crossing in Lead I was favored in that group where the R wave was highest. This occurred in the group with left axis deviation. Although real crossing was not observed, touching was present in 21.2 per cent of the cases, in contrast to the other two electrical positions, where neither real crossing nor touching were observed in any case. In Lead II, the R wave presented its lowest height in the group with left axis deviation and, in effect, no crossing was observed in this group. In the group with the highest R wave, which was observed with normal electrical axis position and with right axis deviation, crossing was present in 5.9 per cent and 12.2 per cent, respectively. The angle τ, intimately related to the T wave, followed the changes of this wave, caused by the shifting of the electrical axis. These changes were opposite in Leads I and II. In Lead I, the highest average angle τ of 53°39′ was observed in cases of left axis deviation and the lowest one of 48°37′, in the group with right axis deviation. In Lead II the situation was reversed. The highest average angle τ of 58°53′ was found in the group presenting right axis deviation, and the lowest angle τ (with an average of 49°28′) was observed in the group with left axis deviation.

The pathologic crossing pattern was studied in patients with hypertension in the initial stages of left ventricular strain with increased R and flattened, but still positive, T waves, and in a miscellaneous group of cardiac patients. The initial stages of left ventricular strain—as predicted—showed a high incidence and degree of direct crossing. The R wave measured in Lead I as 12.6 mm. in height on an average, which compared with the average standard of the present study of 6.07 mm., represents an average increase of 107 per cent. The average height of the T wave was 0.8 mm., i.e., 64.8 per cent less than the average standard. The average R/T ratio measured 19.64 against the average normal of 2.78 and was therefore much increased. According to established threshold correlation between the numerical value of the R/T ratio and the incidence of crossing, this occurs whenever the R/T ratio is greater than 8.0. In effect, with the exception of three cases when the ratio measured 5.7, 6.3, and 7.3 (values

belonging to the intermediate zone), in all cases with ratios above 8.0 (maximum 37.0) real crossing was constantly present. The average crossing distance was large, −8.6 mm. (average normal: 4.75 mm.), and the average crossing height was small, 3.97 mm. (average normal: 10.82 mm.). The angle τ measured 22°44′ on an average (i.e., 56 per cent less than the average normal 50°49′). In Lead II the changes caused by left ventricular strain were less pronounced and, consequently, different crossing patterns were observed. The R wave was only slightly increased, with average height 8.02 mm. (normal average 6.97 mm.). The T wave was definitely flattened, with average height 1.3 mm. (normal average 2.65 mm.). The R/T ratio was on the threshold limit, with an average value of 8.64. Real crossing was observed in 75 per cent of the cases, being "imaginary" in 25 per cent. The angle τ averaged 30°51′, i.e., 45 per cent less than the normal 54°55′.

In the group of patients with cardiac lesions of various etiology, principally with arteriosclerotic heart disease with or without failure, the pathologic type of crossing with markedly altered measurements was present. In Lead I average height of the R wave measured 8.1 mm. and that of the T wave 0.43 mm. Comparing these values with corresponding normal standards, 6.07 mm. and 2.23 mm., respectively, these figures mean an average increase of 33 per cent for the R wave and an average decrease of 80.7 per cent for the T wave. The R/T ratio was significantly increased, with a mean of 22.6, ranging from 8.0 to 52.0. In agreement with this finding, direct crossing was observed in each case. The angle τ was 18°31′ on average, i.e., only 36 per cent and of the average standard. Lead II was comparatively less altered. The R wave presented an average height of 6.0 mm. T wave was 1.13 mm. in height, which is only 42.6 per cent of the normal standard. The R/T ratio was 8.97 on an average. Direct crossing was present in 40 per cent of the cases. The angle τ averaged 32°28′, only 59 per cent of the normal.

To determine the type of crossing, it is usually sufficient to place a rule or a sharp-edged strip of paper tangentially to the descending limb of the T wave and observe its relation to the R wave of the same ventricular complex. Determination of angle τ, or the several measurements here discussed, is not practical in current electrocardiographic interpretation. Crossing in Lead I and II performed by the described methods provides an early diagnostic sign of a minor abnormality of the positive T wave. Direct crossing was always present whenever the positive T wave was abnormally low and it was always absent when the T wave was of normal size. Its presence in records with marked shift of the electrical axis to the left, or with marked increase of the cardiac rate, indicates the initial stages of a pathologic condition. Real crossing expresses qualitatively a loss of the physiologic balance between the R and T waves. It is valuable because it indicates an abnormal situation even when the T wave is still positive. This sign can be compared with other abnormalities of the positive T wave, such as its symmetrical aspect. Its easy determination makes it useful whenever the initial stages of abnormality of a positive T wave come into consideration.

SUMMARY

1. A straight line tangent to the descending limb of the T wave and prolonged toward the R wave of the same ventricular complex may: (1) cross R, (2) touch its peak, or (3) pass above it. Real or direct crossing is present when the crossing line passes below the peak of the R wave and imaginary crossing when the line passes above the peak of the R wave, intersecting its prolongation. Direct crossing does not occur normally.

2. Crossing depends on three factors: degree of elevation of the descending limb of the T wave, as expressed by the angle τ; height of the R wave; and on the distance of the projection of the peak of the R wave on the isoelectric line to the end of the T wave.

3. In one hundred normal electrocardiograms standard values of the crossing distance, of the crossing height, and of angle τ were established in Leads I and II.

4. Crossing presents an inverse correlation to the magnitude of the angle τ. When the angle is less than 25 degrees, direct crossing occurs in every instance; when angle τ is greater than 60 degrees, no crossing occurs. From 26 degrees to 60 degrees the incidence of the crossing decreases gradually.

5. Crossing correlates positively with the R/T ratio; there is no direct crossing with ratios under 5.0. Over 8.0 direct crossing occurs in every instance.

6. Crossing is quantitatively related to cardiac frequency: Direct crossing is absent at low and normal cardiac rates up to 90 beats per minute. In the range from 91 to 120 crossing was observed in 25 to 30 per cent of normal records.

7. Crossing is related to the position of the electrical axis; left axis deviation favors direct crossing in Lead I, whereas right axis deviation does so in Lead II.

8. Crossing between R and T, in the sense of the given definition, reveals a minor, nonspecific abnormality of the positive T wave. It represents an early sign of disturbed correlation within the ventricular complex and indicates initial stages of an abnormal condition of the ventricular myocardium.

SUMMARIO IN INTERLINGUA

Un linea derecte in continuation del latere descendente del unda T pote (1) cruciar le unda R del mesme complexo ventricular, (2) tanger le culmine de ille unda, o (3) passar supra ille culmine. Electrocardiogrammas normal monstra nulle cruciamento. Undas T positive a abassamento anormal (con o sin augmento del unda R) produce un cruciamento directe. Deviation sinistrorse del axe in derivation I e deviation dextrorse del axe in derivation II tende a producer le cruciamento. Illo es promovite per frequentias cardiac de plus que 90. Le cruciamento revela un minor e non-specific anormalitate del unda T positive. Illo representa stadios initial de anormalitate in le myocardio ventricular.

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HORIZONTAL BIPOLAR THORACIC LEADS

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ONE of the methods of clinical exploration that has contributed most towards the success of the diagnosis of heart diseases has been the electrocardiogram.

In its earlier stage the investigation of the cardiac field had been practiced only in the frontal plane by means of distal leads; that is, with both electrodes away from the heart and being applied to the limbs. These were the classical Einthoven leads, also known as bipolar since both electrodes were considered active; that is, they were electrically equidistant from the heart and both supported electric pressures.

This exploration was complete and its interpretation vectorial only in the qualitative sense; in this way, the polarity and direction of the mean electrical forces, the so-called cardiac electric axis, which requires the correlation of at least two leads, was established.

Some time later, Arrighi[1] suggested sagittal exploration of the electric cardiac field and designed three sagittal leads, without, however, improving the electrocardiographic diagnosis.

Finally, the exploration of the electrical cardiac field in the horizontal plane began to be practiced with Wilson's chest leads,[2] thereby improving the clinical electrocardiographic diagnosis, because they pick up the cardiac electric forces in the horizontal plane, the most appropriate from the electric point of view. However, the predominance of local potentials, or local vectors, in these leads due to the voltage of the distal electrode being near the zero point, and especially because the axis of these leads is hypothetical, necessarily makes the interpretation of the electrocardiogram in the horizontal plane topical, or scalar.

Thus, there are two criteria in the interpretation of the clinical electrocardiogram: vectorial in the frontal plane and scalar in the horizontal plane.

At the moment, however, it is not our object to appraise the relative values of each criterion, but it is evident that it is much easier to understand the matter using only one method, and we suggest the vectorial one, because it is more rational and especially because it simplifies the problem. With the object of making a vectorial interpretation of the electrocardiogram in the horizontal

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plane in the same manner as it is interpreted in the frontal plane, we have studied several bipolar leads around the chest in the horizontal plane, at the level of the electrical center of the heart, and later checked them with the vectorcardiogram recorded at the same level.

TECHNIQUE AND METHOD

Three electrodes are used: one anterior over the sternum at the level of the fourth intercostal space, and two posterior, one on the right side at the intersection of this plane with the right posterior axillary line, and the other on the left side at its intersection with the left posterior axillary line.

The right posterior electrode is connected to the right arm wire, the anterior electrode to the left arm wire, and the left posterior electrode to the left leg wire (Fig. 1).

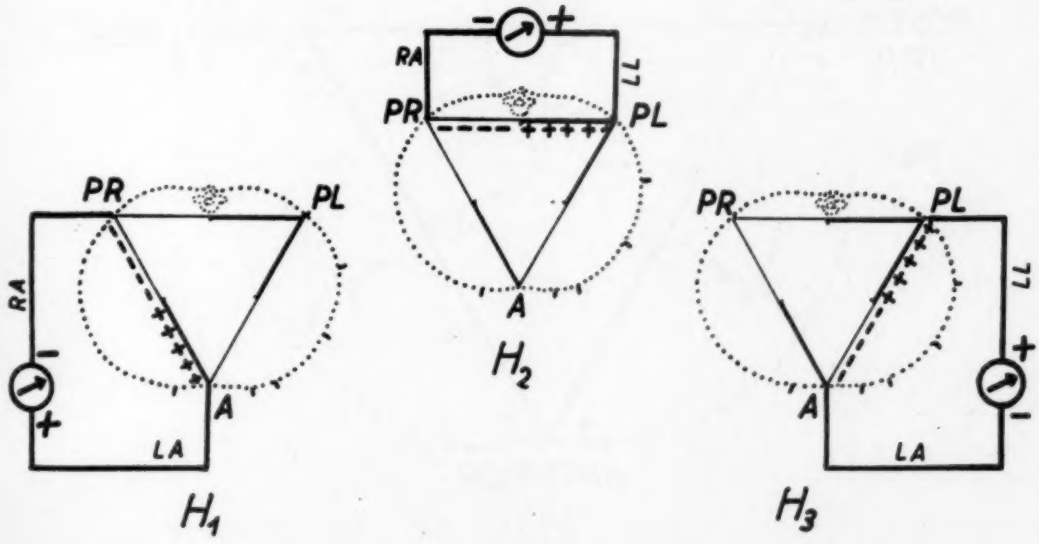


Fig. 1.—Horizontal thoracic bipolar leads (technique).

Lead H_1 is obtained by connecting the anterior electrode with the right posterior electrode on placing the switch in position I. Lead H_2 is obtained by connecting the left posterior electrode with the right posterior electrode on changing the switch to position II. And Lead H_3 is obtained by connecting the left posterior electrode with the anterior electrode on changing the switch to position III.

The resulting polarity is as follows: in H_1 the anterior electrode (A) is relatively positive with respect to the right posterior electrode (PR); in H_2 the left posterior electrode (PL) is relatively positive with respect to the right posterior electrode (PR), and in H_3 the left posterior electrode (PL) is relatively positive with respect to the anterior electrode (A).

Therefore,

$$H_1 = A - PR$$
$$H_2 = PL - PR$$
$$H_3 = PL - A$$
$$H_1 + H_3 = [(A - PR) + (PL - A) = PL - PR] = H_2$$

The mathematical conclusion deduced from this polarity based on Kirchof's Law No. 1, referring to the algebraic sum of the electric forces in a close network, such as occurs in Einthoven's circuit is that $H_2 = H_1 + H_3$.

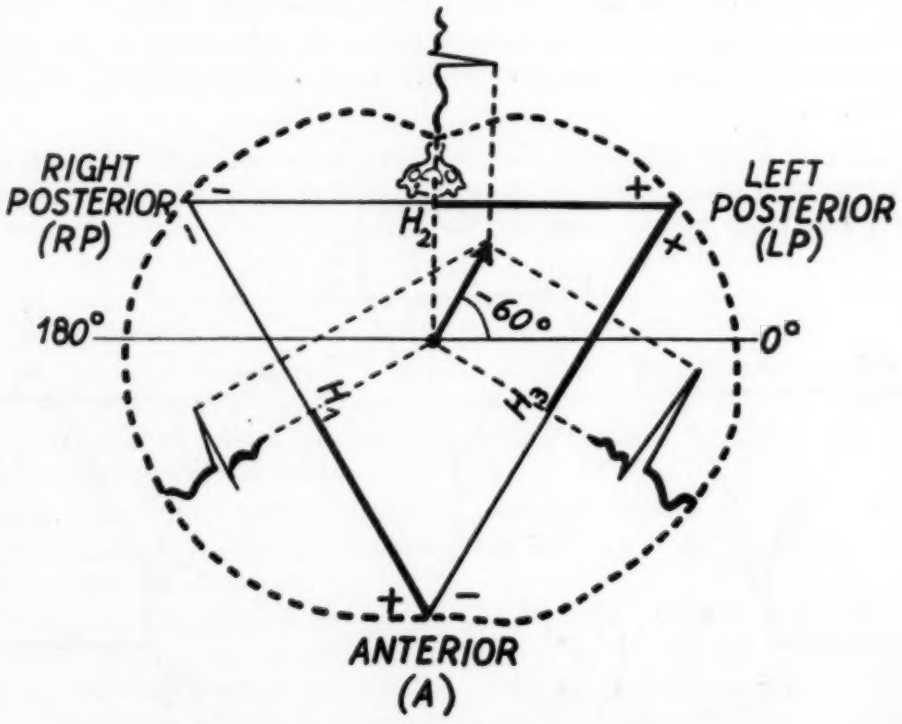


Fig. 2.—Horizontal projection of the mean QRS vector.

Examination of the horizontal leads should begin with a comparison of their form with the normal patterns to which we shall later refer, as well as with the accepted normal findings in the corresponding unipolar Wilson's leads, in particular V_1 and H_1; V_6 and H_2.

Only then should the mean vectors be established for the P wave, the QRS complex, and the T wave, as well as the initial and final vectors of the QRS complex (Fig. 2).

When an isoelectric P or T wave is found, or a biphasic QRS complex with equal positive and negative deflections is present in any one of the leads, it can be accepted, for the purposes of clinical interpretation, that the vectors are perpendicular to the axis of such a lead, and that, if the derivations are greater, it is parallel to the lead in which these deflections are the greatest.[3]

NORMAL CONFIGURATION AND NORMAL VECTORS

In a group of 250 normal subjects, including a small number of children, the normal configuration and the principal vectors of the thoracic horizontal leads were found to be the following (Fig. 3):

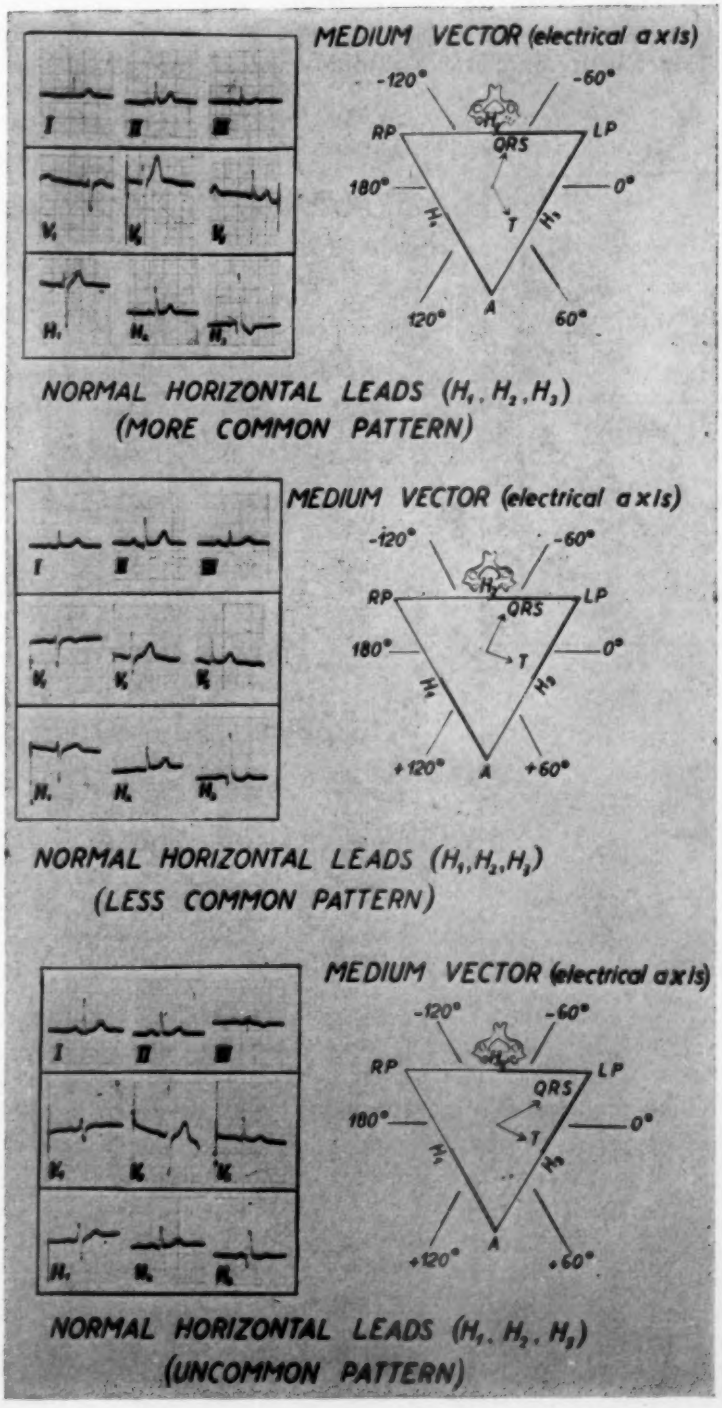


Fig. 3.

P Wave.—In Leads H_1 and H_2 it is always positive and generally biphasic in Lead H_3. Therefore, its electrical axis or mean vector was in the left anterior sextant or, more exactly, close to plus 30 degrees.

QRS Complex.—In Lead H_1 it is generally of the rS type (76 per cent), less frequently of the RS type (20 per cent), and in exceptional cases of the rs or even Rs type (4 per cent).

In Lead H_2 it is generally of the qR type (61 per cent), less frequently of the R type (23 per cent) and in exceptional cases of the qRs, Rs or rs type (15 per cent).

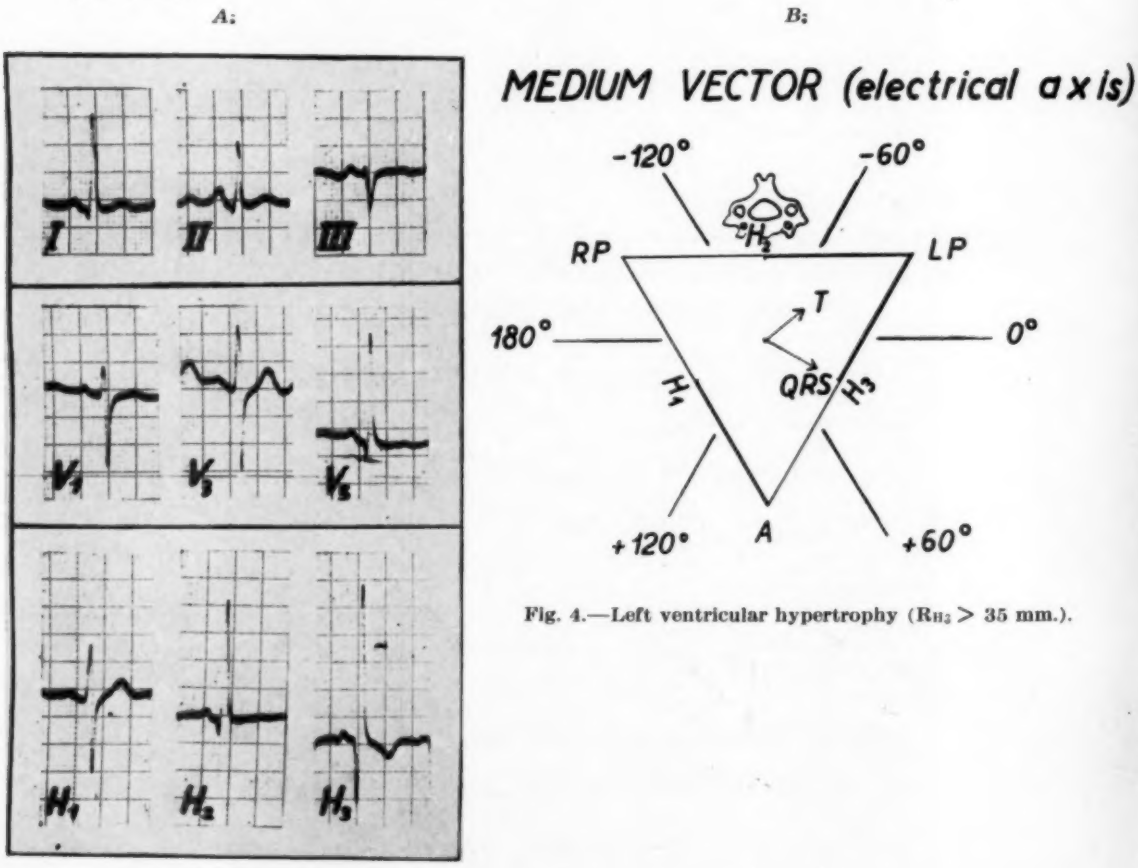


Fig. 4.—Left ventricular hypertrophy ($R_{H_3} > 35$ mm.).

In Lead H_3 it is practically always of the qR type (99 per cent) and in very exceptional cases of the QR type (1 per cent). The voltages in this lead, the only one in which quantitative measurements were taken to be used as criteria for the diagnosis of hypertrophy, were as follows: For the Q wave it is generally from 1 to 4 mm. (85 per cent), at times up to 8 mm. (13 per cent), and in exceptional cases up to 10 or 11 mm. (2 per cent). For the R wave generally it is between 10 and 20 mm. (70 per cent), average 13 to 15 mm., and in exceptional cases up to 30 mm.

The electrical axis or mean vector for the QRS complex in the horizontal plane is always directed close to minus 60 degrees and only rarely to minus 30 degrees.

T Wave.—In Lead H_2 it is always positive. In Lead H_1 it is generally positive (95 per cent), in exceptional cases biphasic or even negative, although this is the rule in children. In Lead H_3 it is commonly negative (55 per cent), but many times positive (30 per cent) or, if not biphasic (15 per cent).

The electrical axis, or mean vector, for the T wave varies from plus 90 degrees to minus 50 degrees, but most frequently falls between 0 degrees and plus 60 degrees (60 per cent).

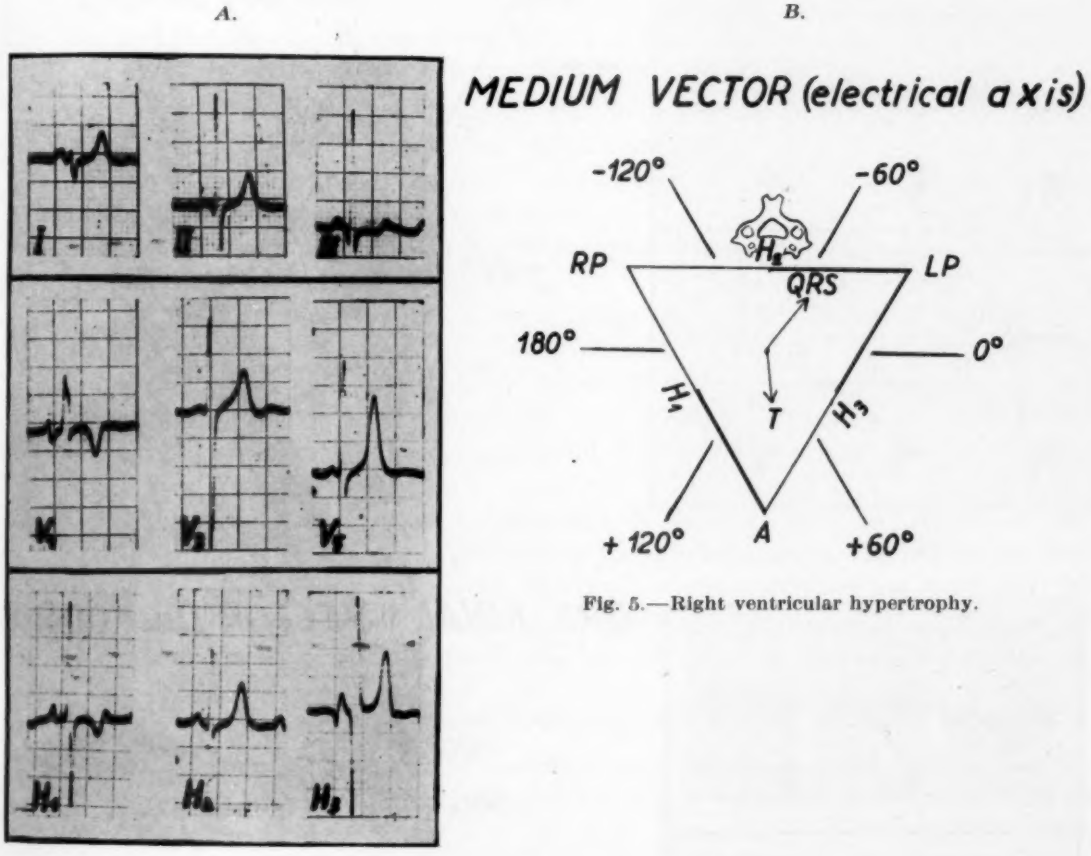


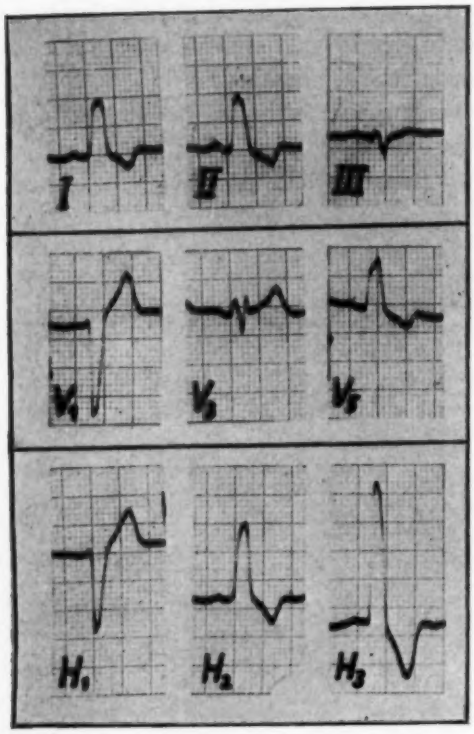
Fig. 5.—Right ventricular hypertrophy.

VENTRICULAR HYPERTROPHY

In a group of 200 cases of ventricular hypertrophy studied (150 of the left ventricular hypertrophy and 50 of the right ventricular hypertrophy) we have arrived at the following conclusions:

Left Ventricular Hypertrophy.—The general configuration of the QRS complex is not greatly altered. There is no notching and the duration may be up to 0.10 second. There is only a reduction in the size of the R wave or even an absence of R with a deep S in Lead H_1. The q and R waves in Lead H_3 are larger than the maximum normals accepted. There is also a deep Q and a tall R in H_2. All these findings are an expression of the posterior displacement of the electrical axis or principal vector due to the predominance of the muscular mass of the left ventricle placed to the left, mainly behind, and somewhat above the right ventricle (Fig. 4).

A. B.



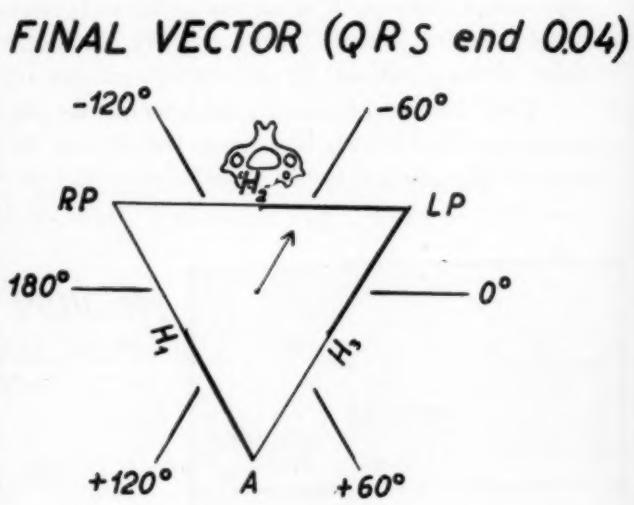
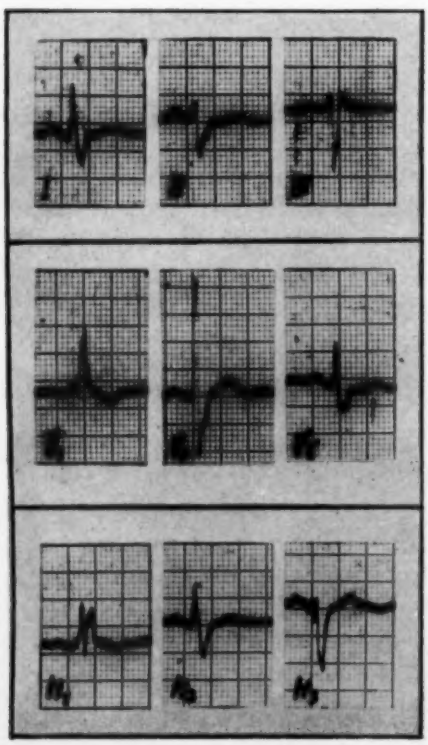


Fig. 6.—Left bundle branch block.

A. B.



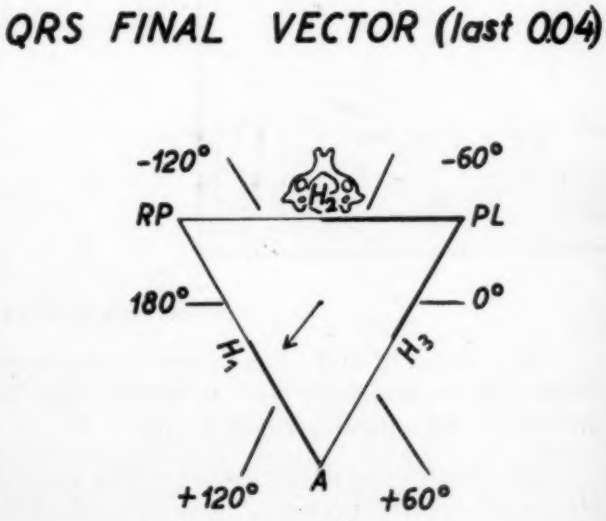


Fig. 7.—Right bundle branch block.

When left ventricular hypertrophy is present with alterations of the repolarization, the T wave is always positive in H_1, deeply negative in H_3, and also negative but not as deeply in H_2, indicating that its electrical axis or mean vector is always some degrees above plus 90 degrees, that is, practically in an opposite direction to the mean vector of the QRS complex, which means that the angle QRS-T is of 180 degrees or more.

When the voltages of R in H_3 is more than 35 mm., this is significant of left ventricular hypertrophy. This is comparable to what occurs with the sum of Sv_1 and Rv_5 or Rv_6, since, as we have pointed out previously, $H_3 = LP - A$, i.e., the sum of the absolute potential of the leads located in V_1 and V_5 or V_6.

Right Ventricular Hypertrophy.—Neither is the general configuration altered in this case. There is no notching and the duration is normal. However, there are significant changes in the form and direction of the mean vector as a result of the changes in the cardiac position occurring as a consequence of hypertrophy. When hypertrophy is marked the increased ventricular muscle mass present is also responsible for these changes (Fig. 5).

In Lead H_1 there is a tall R wave preceded at times by a small q wave and there is no S wave present. In Leads H_2 and H_3, on the other hand, the R is small and the S wide and of large amplitude. This indicates a change in the direction of rotation of the successive vectors and an anterior rotation of the electrical axis or mean vector to beyond plus 30 degrees and even up to plus 90 degrees or more.

When right ventricular hypertrophy is present with alterations of the repolarization, the T wave is positive in H_3 and negative in H_1, indicating that the electrical axis or mean vector has rotated posteriorly to less than plus 30 degrees and beyond minus 30 degrees or, practically in an opposite direction to the mean QRS vector with the result that the QRS-T angle is almost of 180 degrees.

BUNDLE BRANCH BLOCK

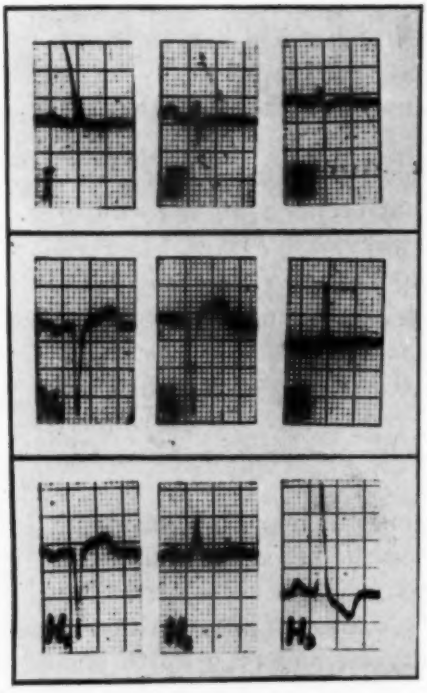
In a group of 100 cases of bundle branch block studied, 55 of left bundle branch block and 45 of right bundle branch block, we have arrived at the following conclusions:

Left Bundle Branch Block.—The general configuration of the QRS complex is markedly altered. In the first place it is wide, 0.12 second or more in complete bundle branch block, and there is considerable notching (Fig. 6).

In H_1 R is small and narrow, while S is wide, deep, and notched with a positive T. In H_2 and H_3, Q is small and narrow or absent, while R is tall, wide and notched with negative opposite T, indicating that the final vector of the QRS complex is directed posteriorly between 0 degrees and minus 90 degrees, an average of minus 30 degrees, indicating that the left ventricle is the last one activated.

Right Bundle Branch Block.—The QRS complex shows the same widening and notching observed in the left bundle branch block, but it has the following configuration: in H_1 it is M shaped due to the presence of R and R′, or it may be only a wide R with deep notching on the descending limb, while in H_3 it is W shaped and in H_2 it is of the RS type, but with a wide notched S wave (Fig. 7).

A.



B.

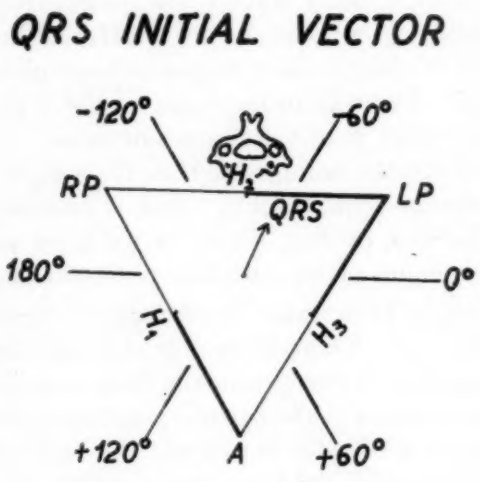
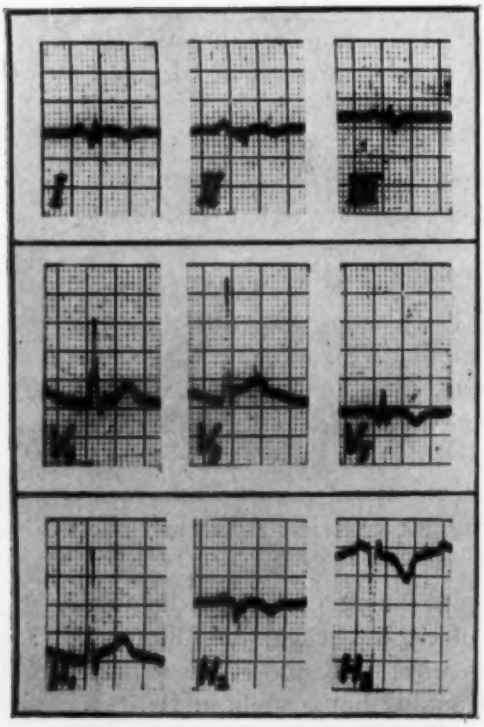


Fig. 8.—Anteroseptal myocardial infarction.

A.



B.

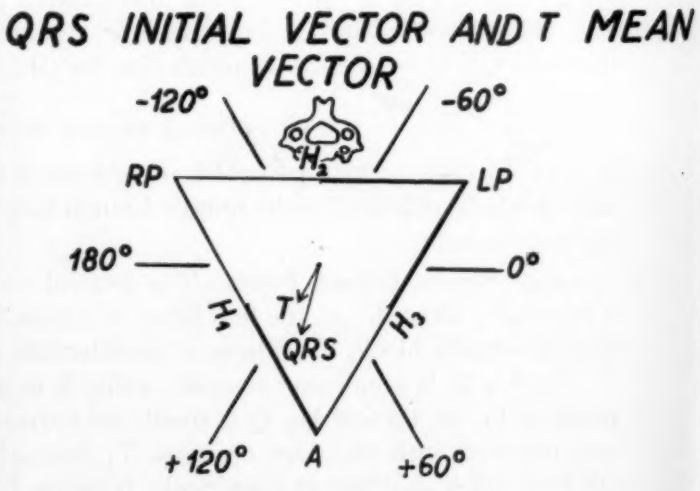


Fig. 9.—Posterolateral myocardial infarct.

These findings demonstrate that the final vector is directed anteriorly and to the right between plus 90 degrees and plus 180 degrees, an average of 120 degrees, which indicates that the right ventricle is the last one activated.

MYOCARDIAL INFARCTION

One hundred cases of myocardial infarction were studied. Criteria for the acceptance of this diagnosis, from a strictly electrocardiographic viewpoint, were the following: Negative T wave, peaked and symmetrical due to ischemia; elevation of S-T segment due to myocardial injury and deep, wide Q from myocardial necrosis. The following observations were made in the different types of infarctions.

For a better understanding of the matter let us, first of all, recall that the ischemia vector and the necrosis vector are directed away from the diseased area toward the healthy areas, the ischemic vector during repolarization and, therefore, the negative T, the necrosis vector during the first 0.04 second of the activation and, therefore, the deep, wide Q. This is true only if these are projected on the positive side of the axis in the leads. On the other hand, the vector of injury, diastolic in origin but artificially transformed to systolic, for which reason it is preferably called the S-T vector, is directed away from the healthy areas and toward the diseased areas, thus accounting for the elevation of the S-T segment when it is projected on the positive side of the axis in that lead.

Anteroseptal Infarction.—H_2 is normal since its axis is perpendicular to the direction of the pathologic vectors (Fig. 8).

In Lead H_1 there is a wide Q or QS with a negative T since it is directed away from the diseased area (anterior) and toward the healthy areas (posterior), thus representing the corresponding vectors of necrosis and ischemia. The S-T segment is elevated since it is directed away from the healthy areas and toward the diseased areas and the vector of injury.

In Lead H_3, on the other hand, due to the inversion of polarity there is an R wave without q, a depressed S-T segment, and a positive peaked T wave, the so-called indirect electrical signs of myocardial infarction.

Lateral Infarction.—In Lead H_2 there is a wide QS or Q and negative T since it is directed away from the lateral diseased area toward the healthy area on the right side, the corresponding vectors of necrosis and ischemia. On the other hand, there is an elevated S-T segment, since it is the vector of injury directed away from the healthy areas and toward the diseased areas (Fig. 9).

Posterior Infarction.—In Lead H_3 there is a wide Q or QS with negative T, since the corresponding vectors of necrosis and ischemia are directed away from the posterior region, the diseased area, and toward the anterior region, or the healthy area. In contradistinction the elevated S-T segment and consequently the vector of injury are directed away from the healthy areas and toward the diseased area (Fig. 10).

In Lead H_1 the same configuration occurs only as it is inverted, i.e., the R wave without q, depressed S-T, and positive T, since its polarity is exactly opposite to that of H_3.

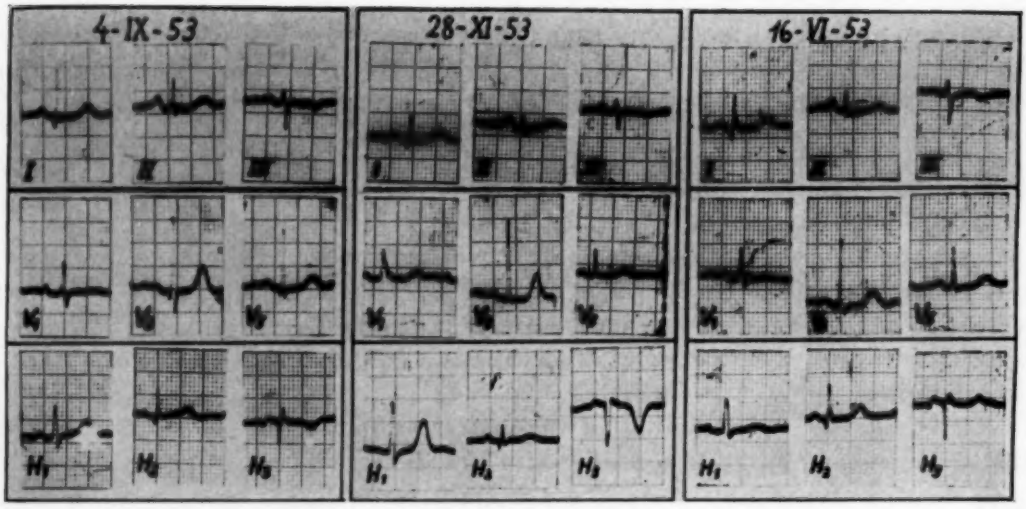


Fig. 10.—*4-IX-53* = Old posterior infarction: QRS initial vector plus 100 degrees and T vector plus 60 degrees (horizontal leads). *28-XI-53* = Clinical symptoms of new acute infarction: QRS initial vector plus 120 degrees and T vector plus 80 degrees (horizontal leads). *9-XII-53* = Clinical healing of the second infarction: QRS initial vector plus 120 degrees and T vector O degrees (horizontal leads).

SUMMARY AND CONCLUSIONS

1. Three bipolar leads are situated in the same horizontal plane, distributed in the form of an equilateral triangle at the level of the electrical zero point of the heart, which determines the complete electric field in this plane and enables us to establish the principle of vectors with a sufficient degree of accuracy when compared with vectorcardiographic controls.

2. In a group of 250 normal persons studied for the configuration of the mean vector of the P wave, the QRS complex and the T wave enabled us to establish constant values in contrast to the wide range occurring in the frontal plane.

3. In a group of 200 cases of ventricular hypertrophy, the general configuration of the QRS complex was practically unaltered, with only the following changes:

a. In left ventricular hypertrophy, the R wave was smaller or absent in H_1 and in H_3 it was larger with a deep, but not wide q. The voltage of R is above 35 mm. (sign of hypertrophy), and the mean vector of QRS was rotated posteriorly.

b. In right ventricular hypertrophy, R was predominant in Lead H_1 and the mean vector of the QRS complex was definitely rotated anteriorly up to plus 60 degrees and even plus 90 degrees.

If ventricular strain was present the mean vector of T became almost opposite up to 180 degrees, and in Lead H_2 in the cases of left ventricular hypertrophy, T was negative.

4. In a group of 100 cases of bundle branch block the QRS complex was wide and notched with the special characteristic that its final vector was directed posteriorly in the left bundle branch block and anteriorly in the right bundle branch block; i.e., it pointed toward the ventricle, which was last to be activated.

5. In a group of 100 cases of myocardial infarction, in the positive part of each lead, H_1 in the case of anterior infarction, H_2 in lateral infarction, and H_3 in posterior infarction, the initial vector of the QRS complex was directed away from the diseased area (wide Q), the S-T segment vector was directed toward it (S-T elevated), and the T vector was also directed away from it (negative T).

SUMMARIO IN INTERLINGUA

Esseva usate tres derivationes bipolar, disponite in un triangulo equilatere circa le thorace al nivello del quarte spatio intercostal, pro obtener un interpretation vectorial del electrocardiogramma in le plano horizontal. Le vectores median de P, QRS, e T e le vectores initial e final de QRS esseva analysate in 250 subjectos normal, 200 patientes con hypertrophia ventricular, 100 patientes con bloco de branca, e 100 patientes con infarcimento del myocardio.

In le subjectos normal, le position e direction esseva multo plus constante in le plano horizontal que in le plano frontal.

In hypertrophia dextero-ventricular, le vector median del complexo QRS monstrava regularmento un rotation anterior de usque plus 60 e mesmo plus 90 grados. Le vector median de T se monstrava opposite (angulo QRS-T: 180 grados).

In le casos de bloco de branca sinistre, le vector final de QRS habeva semper un direction postero-sinistre. In le casos de bloco de branca dextere, illo habeva semper un direction antero-dextere. I.e., le direction del vector final de QRS esseva semper verso le ventriculo in que le activation occurreva plus tarde.

In casos de infarcimento myocardiac, le vector initial de QRS esseva orientate in le direction opponite al sito del infarcimento, i.e. in un direction posterior in casos de infarcimento anterior, in un direction anterior in casos de infarcimento posterior, e in un direction dextrorse in casos de infarcimento lateral.

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PREMATURE BEATS OVERCOMING IMPAIRED INTRAVENTRICULAR CONDUCTION. SUPERNORMAL PHASE OF INTRAVENTRICULAR CONDUCTION

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THE occurrence of premature beats with normal intraventricular conduction is uncommon in tracings showing impaired intraventricular conduction in the basic rhythm.

Only a few such cases have been reported. Wilson and Hermann[1] published the first in 1920; the premature beats were thought to arise in the intraventricular septum just below the blocked region, so that there was no delay in either side. A second case was reported by Hewlett[2] in 1921, and was similarly interpreted; however, the possibility of two simultaneously discharging foci, one in each ventricle, was also considered. Three cases were reported in 1944 by Simon and Langendorf.[3] The mechanism advocated by Wilson and Hermann was considered as the most likely; in one instance, regular conduction of the impulse during a supernormal phase of recovery of the injured bundle was suggested. Recently Rosenmann and associates,[4] in a study on impaired intraventricular conduction, presented a case of intraventricular block of the left bundle branch system, in which there were premature beats with short QRS interval and with a contour-simulating intraventricular block of the right bundle branch system. Since normalization of the intraventricular conduction did not occur in the premature beats, this case resembled an alternating bundle branch block, as described by Katz, Hamburger, and Rubinfeld.[5]

Since a careful analysis of such records may provide a rare opportunity to determine the various phases of refractoriness of the human heart, and since the occurrence of such arrhythmias is extremely uncommon, the reporting of two additional cases having special features is considered worthwhile.

CASE REPORTS

CASE 1.—B.B., aged 62 years. Clinical diagnosis was arteriosclerotic heart disease. An electrocardiogram taken on Oct. 8, 1951, (Fig. 1) showed the following data:

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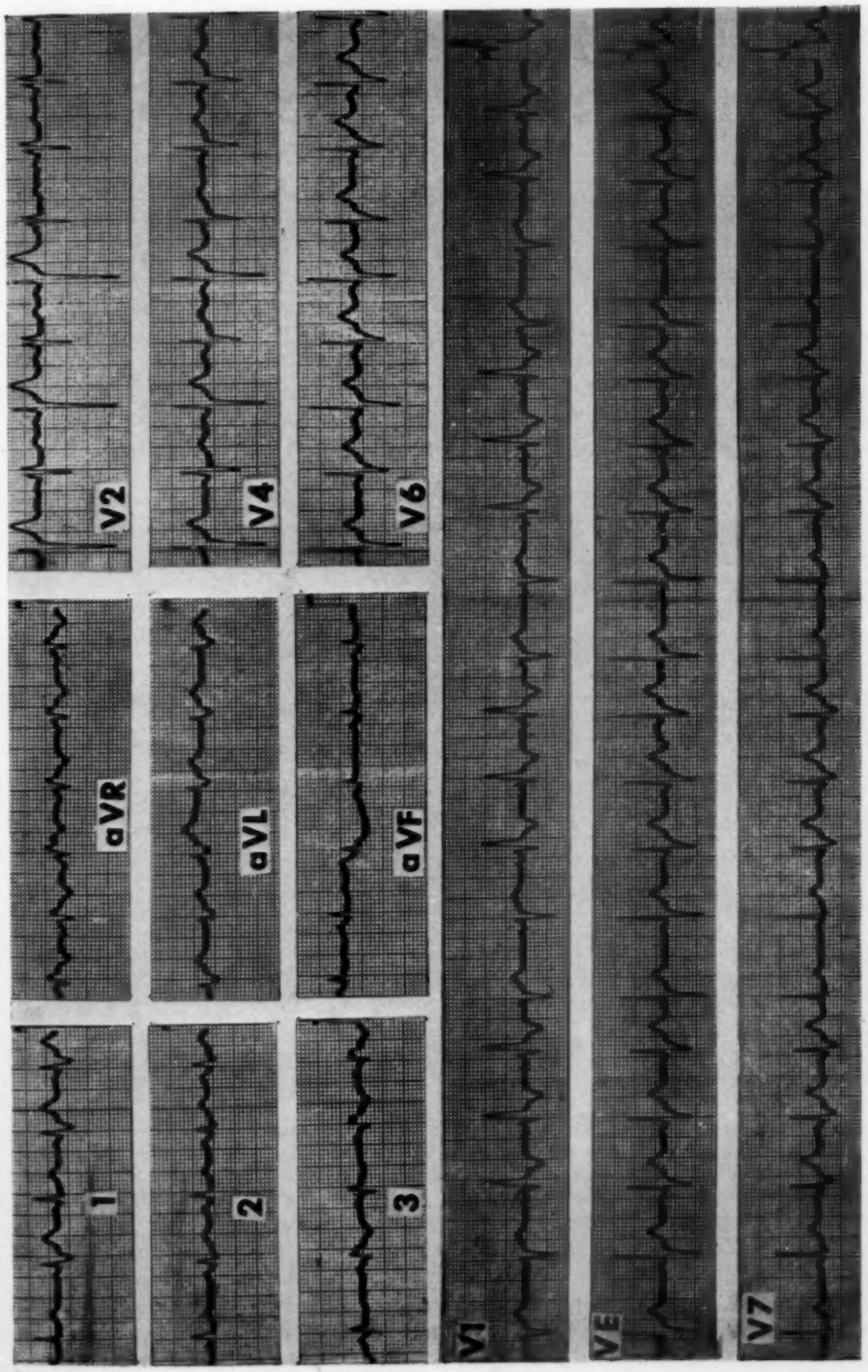

Fig. 1.—Case 1. ECG obtained on Oct. 8, 1951. The regular sequence of the sinus P's is occasionally interrupted in the precordial and in the standard limb leads by premature P waves of slightly different contour. Except in the aV limb leads, two types of QRS are seen, one with normal duration and configuration, the other with prolonged duration and bizarre contour. Note that the ventricular complexes with normal QRS occur either early in the cycle or late, whereas those with prolonged QRS terminate cycles of intermediate length. (For details see text.)

a. In the standard leads the sinus P waves occur at a fairly regular rate of 96 per minute. Only the first P wave is premature and probably of upper nodal origin. Two different configurations of the ventricular complexes are seen: some have a QRS duration of 0.14 second and a contour similar to that found in intraventricular block of the right bundle branch system; the others have a QRS duration of 0.08 second and a normal contour. The latter occur both in the premature and in the sinus conducted beats.

b. Inspection of the A-V leads reveals a regular sinus rhythm and a wide QRS indicating faulty intraventricular conduction in the right bundle branch system.

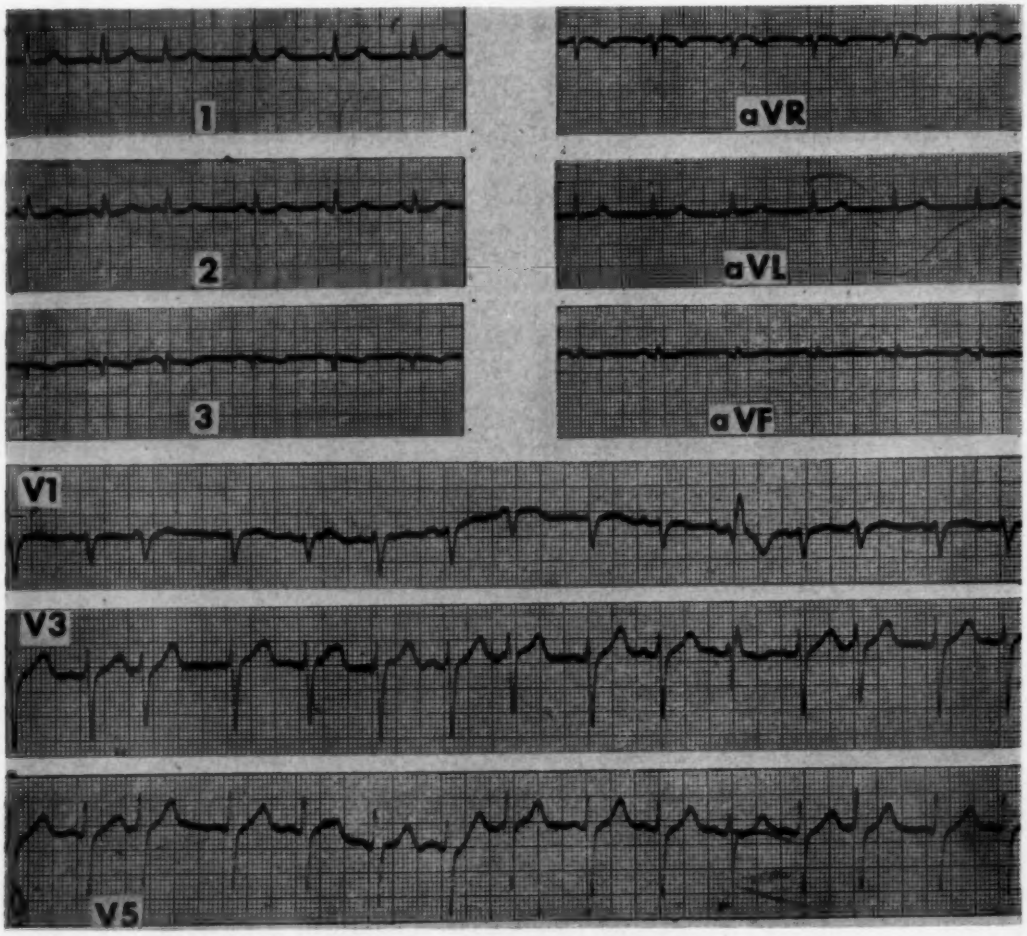

Fig. 2.—Case 1. Follow-up ECG obtained on Oct. 26, 1951. Except for three beats (eleventh complex in V_1, V_2, and V_3), all P waves are now followed by QRS complexes of normal duration and configuration. Premature beats are again present, showing essentially the same contour as the dominant beats and resembling the premature complexes seen in Fig. 1. This would rule out the possibility of conduction of the premature impulse through accessory pathways in Fig. 1.

c. In Leads V_2, V_4, and V_6 the sinus P waves are regularly spaced, but the ventricular rate is irregular because of the presence of premature beats, one with normal (first complex) and another with defective conduction (sixth complex). Both of them show interference with the sinus impulses. Among the conducted sinus impulses two have normal intraventricular conduction, while the others show impaired conduction in the right bundle branch system.

d. A very unusual type of arrhythmia is present in Leads V_1, V_E, and V_7. These leads show a sinus rhythm (rate 94), a normal P-R interval (0.14 second), and a QRS duration and configuration indicating intraventricular block of the right bundle branch system. A premature

beat preceded by a premature P wave and with a normal duration and configuration of QRS occurs every fourth beat. The QRS of the first sinus conducted beat following the premature contraction has a normal duration and configuration.

A second tracing was taken on Oct. 24, 1951, (Fig. 2). It revealed a sinus rhythm (rate 76) with disappearance of the intraventricular conduction defect. Only three of the sinus conducted beats in the precordial leads (eleventh complexes in V_1, V_3, and V_5) present a QRS duration of 0.14 second and a contour similar to that seen in intraventricular block of the right bundle branch system. Occasional premature beats with normal QRS duration and preceded by a premature P are visible in both the standard (third complex) and the precordial leads (third complex). Other premature QRS's with normal intraventricular conduction should be considered as nodal beats interfering with the sinus impulse, since the P wave spacing is not modified (eighth and thirteenth complex in the precordial leads). Neither carotid sinus pressure nor amyl nitrite inhalation modified the tracing, with the exception of increase in rate.

CASE 2.—C.F., aged 45 years. Clinical diagnosis was thyrotoxicosis. An electrocardiogram taken on March 19, 1953, (Fig. 3) showed a slightly irregular sequence of sinus beats (84 to 92 per minute), occasionally disturbed by conducted auricular premature beats. While the P-R interval of the sinus beats is 0.11 second, that of the premature is 0.13 second. The QRS duration of the sinus beats (with the exception of the first postextrasystolic complex) is 0.13 second, and its contour in all leads suggests an intraventricular block of the right bundle branch system. By contrast, the QRS duration and configuration of the premature beats is normal, with the exception of the third complex in aV_F and the third and sixth complexes in V_6. While the coupling of the third complex in aV_F to the preceding sinus conducted beat is 0.435 second, that of any other premature beat is longer, ranging from 0.47 to 0.51 second. Both the third and sixth complexes terminate short cycles which follow upon cycles the respective durations of 0.725 and 0.775 second. These latter durations are longer than those of the preceding cycles of any other premature beat in the record.

DISCUSSION

In a tracing presenting faulty intraventricular conduction in the fundamental rhythm, premature beats with normal intraventricular conduction can theoretically be explained on the basis of four mechanisms: (1) a septal origin (below the site of block) of the premature beats; (2) conduction of the premature impulse through accessory pathways connecting the right auricle to the right ventricle; (3) a bilateral lesion of the bundle branch system; (4) occurrence of the premature beats during the supernormal phase or recovery of the blocked region.

The first hypothesis, which is commonly accepted, seems unlikely in our cases. In Case 1, although premature QRS's with normal intraventricular conduction interfering with sinus impulses are clearly seen (first complex in V_2, V_4, and V_6; eighth and thirteenth complexes in the chest leads in Fig. 2), others are preceded by a premature P and are, therefore, to be considered of upper nodal origin (first, sixth, eleventh, and sixteenth complexes in V_1, V_E, and V_7 in Fig. 1). While it is difficult to exclude a septal origin of the premature beats with normal QRS duration and interfering with the sinus impulses, a supraventricular origin must be admitted whenever the premature QRS is preceded by a premature P.

The possibility of conduction of the premature impulse through accessory pathways should be considered in Case 1. Here the premature P waves do not have a contour indicating retrograde conduction, although the P-R interval is short. The earlier spread of the impulse into the right ventricle could overcome

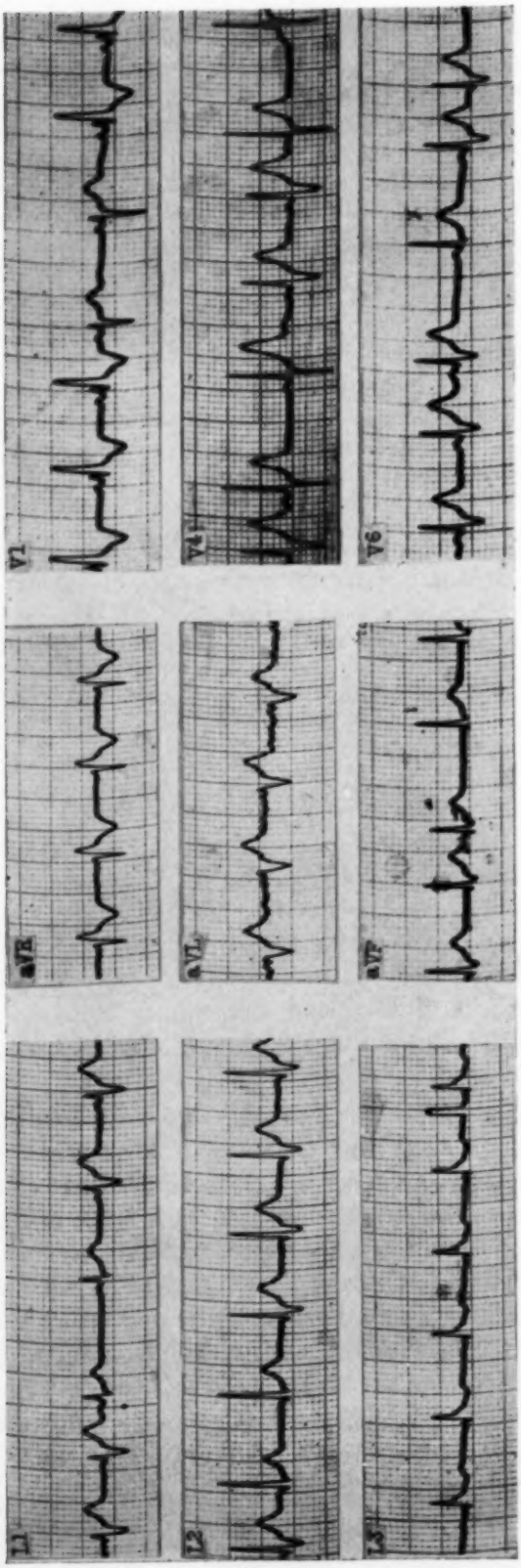

Fig. 3.—Case 2. ECG obtained on March 19, 1953. The sinus rhythm is occasionally disturbed by conducted auricular premature beats. With the exception of the third complex in aV_F and the third and sixth in V_6, QRS of normal duration and configuration follows the premature P's and the sinus P's, terminating the first postextrasystolic cycle. By contrast, the QRS duration of the sinus conducted beats is prolonged. (For details see text.)

the delay of the right bundle branch system. However, this possibility may be excluded since in the following tracing (Fig. 2), in which normal intraventricular conduction was re-established, the premature beats preceded by premature P and short P-R interval do not show early spread of the stimulus into the right ventricle.

The possibility of a bilateral lesion of the bundle branch system should be taken into consideration in both cases. When R-R interval is of longer duration, the stimulus may reach the left bundle when this is no longer refractory; because of a shortening of the ventricular cycle, a premature impulse could find the left bundle still refractory. It is understood that in such a case, a prolongation of the P-R interval should result.[6-8] This hypothesis, therefore, should be considered improbable in Case 1, where no prolongation of the A-V conduction time is observed in the premature systoles. In Case 2, where a prolongation of the P-R interval of about 0.02 second is observed in the premature beats, this mechanism may also be considered. However, the small magnitude of the prolongation speaks against it.

In Case 1, where a septal origin of the premature impulse, its conduction through accessory pathways, and a bilateral lesion of the conducting system can be disregarded, the normalization of the intraventricular conduction can be accounted for by the fact that the premature impulse enters the blocked region during its supernormal phase of recovery. The presence of a supernormal phase of recovery in damaged hearts has been proved both in animals[9] and in man.[10-12] Conduction during a supernormal phase can be used to explain the normalization of the intraventricular conduction of the premature beats in Case 2 also, if it is assumed that the prolongation of the P-R interval in the premature beats is the result of a slow conduction through the junctional tissue, rather than a bilateral lesion of the bundles.

It should be noted that in Leads V_1, V_E, and V_7 of Case 1 (Fig. 1) and in Case 2 (Fig. 3) the first sinus beat following a premature contraction has a normal QRS duration and configuration. It is believed that this is due to a depression of the sinus pacemaker by the premature impulse which affords enough time for the conducting system to recover. Following this, the reappearance of the intraventricular block in the next beat can be accounted for by a prolongation of the refractory stage due to a longer preceding cycle.[13]

These considerations would indicate the importance of the refractory phase of the blocked region in comparison to the site of origin of the premature impulse.

Having concluded this, we proceeded to analyze the intraventricular conduction in these cases as a function of the duration of the ventricular cycle. It is clear that if we are dealing with a phenomenon of supernormal recovery, a normal conduction should be observed between the phases of absolute and relative refractoriness. Included in this analysis were a number of beats not illustrated in the figures.

It is evident from the diagrams (Figs. 4 and 5) that, with few exceptions, normal conduction occurs with either short or long cycles, whereas impaired conduction takes place with cycles of intermediate duration. It can be inferred that the delayed conduction occurs during the relative refractory period of the

right bundle, while the normal beats occur either during the supernormal phase (short cycles) or during the full recovery phase (long cycles).

It is further noted that a number of beats with defective intraventricular conduction occur with the shortest cycles. These beats are regarded as falling

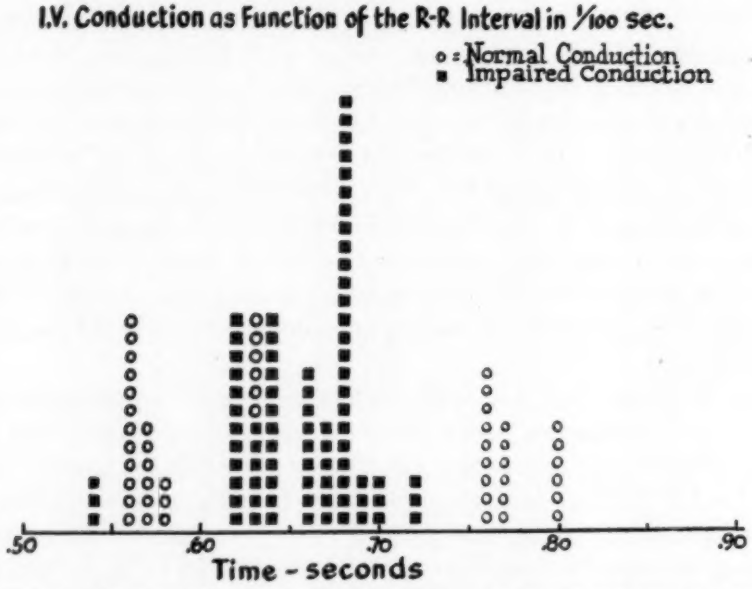

Fig. 4.—Case 1. Diagram representing the distribution of normal and impaired intraventricular conduction during the various portions of the cardiac cycle. Note that, with but a few exceptions, normal conduction occurs either early or late in the cycle. (For details see text.)

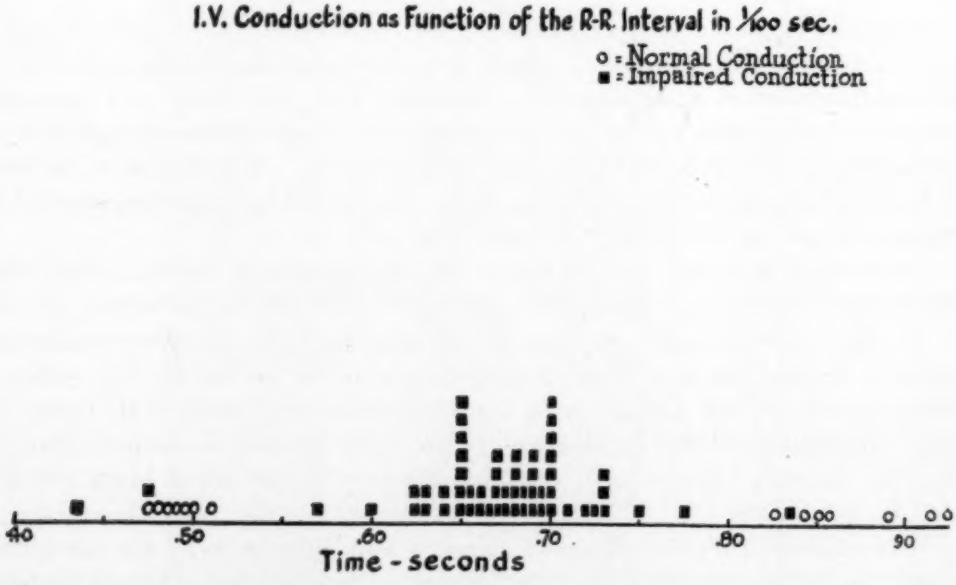

Fig. 5.—Case 2. Diagram representing the distribution of normal and impaired intraventricular conduction during the various portions of the cardiac cycle. Note that, with but a few exceptions, normal conduction occurs either early or late in the cycle. (For details see text.)

within the absolute refractory period of the right bundle. In Fig. 5, a beat (sixth complex in V_6, Fig. 3) terminating a ventricular cycle of 0.470 second is seen to be conducted defectively, although another premature beat with equal coupling is conducted normally. An analysis of the preceding R-R of this beat reveals that this is longer than that of any other premature beat. The longer absolute refractory period that follows upon a long preceding R-R can explain the unexpected abnormal conduction of this beat.

The third complex in aV_F of Fig. 3 has defective intraventricular conduction, but with an even shorter cycle length (0.435 second). This can be explained by assuming that the beat falls in the absolute refractory phase of the right bundle branch system. This latter explanation also holds for the three beats in Fig. 4, which show defective intraventricular conduction with the shortest recorded R-R intervals.

It may, therefore, be concluded that in Case 1 (Fig. 4) the absolute refractory period lies between 0 second and 0.54 to 0.56 second, the supernormal phase between 0.56 and 0.62 second, the relative refractory phase between 0.62 second and 0.72 to 0.76 second, with absolute recovery beginning between 0.72 and 0.76 second.

For Case 2 (Fig. 5), the corresponding figures are: absolute refractory period from 0 second to between 0.435 and 0.47 second; supernormal phase from 0.47 to 0.57 second; relative refractory period from 0.57 second to between 0.775 and 0.825 second; and absolute recovery period beginning between 0.775 and 0.825 second.

SUMMARY

1. Two cases of complex arrhythmia are reported, in which premature beats of normal QRS duration and configuration occur in contrast to the bundle branch block pattern of the dominant rhythm.

2. Septal origin of the premature beats, below the blocked region, conduction of the premature impulse through accessory pathways, bilateral lesion of the conducting system, and occurrence of the premature beats during the supernormal phase of intraventricular conduction, are discussed. The last explanation is accepted as the more likely.

3. The duration of the various phases of refractoriness was calculated in both cases.

SUMMARIO IN INTERLINGUA

1. Es reportate duo casos de arrhythmia complexe in que pulsos prematur a duration e configuration normal de QRS occurre in contrasto al configuration de bloco de branca in le rhythmo dominante.

2. Es discutite plure possibile explicationes: (1) Origine septal del pulsos prematur, infra le region blocate. (2) Conduction del impulso prematur per vias accessori. (3) Lesion bilatere del systema de conduction. (4) Occurrentia del pulsos prematur durante le phase supernormal del conduction intraventricular.—Le ultime es acceptate como le plus probabile.

3. Le duration del varie phases de refractorietate esseva calculate in ambe casos.

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THE EFFECTS OF ARCTIC CLIMATE AND DIFFERENT SHELTER TEMPERATURES ON THE ELECTROCARDIOGRAM

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THE effect of cold on the cardiovascular system has been a subject of investigation for many years. With increasing attention presently being focused on medical problems in the Arctic, determination of the effects of lowered environmental temperatures on the heart is of immediate interest.

The Army Medical Service test program, carried out at Ft. Churchill, Manitoba, Canada, during the winter of 1954, included studies to determine electrocardiographic changes after outdoor work in the Arctic. The study was also directed toward determining the minimal temperatures of arctic shelters that would enable men to work with efficiency and comfort. The effects of arctic climate and of two different shelter temperatures on the electrocardiogram are reported here.

METHODS

Seven healthy, white men, 20 and 21 years of age, were the test subjects. None had history or symptoms of cardiovascular disease. None had previously lived in an arctic climate.

The tests in the Arctic were conducted in three phases. During the first phase of 28 days, three subjects lived in a prefabricated aluminum shelter heated to a comfortable temperature of 70°F. (at the sitting chest level) while four other subjects lived in a similar shelter heated to 50°F. For the second phase, the two groups exchanged shelters for another 28-day period. Following this, the subjects occupied their original shelters for one week. During the exercises to be described both groups wore the same type of clothing, the standard arctic issue. The temperature averaged −16.4°F. (with a low of −34°F.) during the tests. Although Ft. Churchill is situated below the Arctic Circle at a North Latitude of approximately 60°, high wind velocities render the climate "arctic" in character.

Four grades of exercise were performed, all outdoors on a two-step platform. One exercise consisted of walking up and down the platform ten times per minute for twelve minutes (80 steps per minute). This rate of work corresponds to a brisk march at 3.5 to 4.0 miles per hour. In order to determine response to "exhausting" work, each subject also ran up and down the steps at double this

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TABLE I. SUMMARY OF ELECTROCARDIOGRAPHIC FINDINGS OF NORMAL MEN, HOUSED AT DIFFERENT SHELTER TEMPERATURES, AFTER VARIOUS GRADES OF WORK IN ARCTIC AND TEMPERATE CLIMATES

	TEST											
	STEPS AT 80/MIN. (4 m.p.h.)			STEPS AT 160/MIN. (8 m.p.h.)			"SINGLE MASTER"			"DOUBLE MASTER"		
	ARCTIC		TEMPERATE	ARCTIC		TEMPERATE	ARCTIC		TEMPERATE	ARCTIC		TEMPERATE
CLIMATE AND SHELTER	WARM	COLD		WARM	COLD		WARM	COLD		WARM	COLD	
Total "normal" tracings	6	6	5	1	0	2	3	2	7	5	3	7
Total "abnormal" tracings	0	1	0	4	8	7	0	0	0	0	1	0
Total "borderline" tracings	1	0	2	4	4	5	1	1	0	2	3	0
Per cent "normal" tracings	85.7			4.8			71.4			57.0		
	85.7	85.7	71.4	11.1	0	14.3	75.0	66.7	100	71.0	42.9	100

rate for twelve minutes. Single and double Master tests,[1] slightly modified,* were performed for one and one-half and three minutes, respectively, as is the customary procedure, the number of trips being determined in accordance with Master's tables.

All the tests were performed by each subject during both the "warm" and "cold" shelter phases, except for the single Master test which was performed once. The same tests were also performed by the same subjects in a temperate climate. Although the clothing differed somewhat in the temperate tests, each subject carried a pack to maintain the same clothed weight as in the Arctic.

The three standard leads, the three unipolar limb leads and Lead V_4 were recorded on a Sanborn Twin-Viso Recorder prior to exercise, immediately following exercise, and five minutes after exercise. Postexercise electrocardiograms were recorded with the subject standing, outdoors. Arctic resting records were taken with the subject supine, indoors and standing, outdoors.

Cycle length and Q-T intervals were determined after at least five consecutive complexes were measured. Smoking and eating were prohibited for two hours prior to the tests.

RESULTS

Resting records were judged by the standards of the New York Heart Association.[2] Extensive investigations[1,3,4] have led to the adoption of criteria for interpreting the Master "two-step" tests. Postexercise depression of the RS-T segment of more than 0.5 mm., the P-R interval being the isoelectric level, is considered an abnormal result. Although there is some difference of opinion concerning the accuracy of this criterion,[5] particularly as applied to the double two-step test,[4,6] it has the advantage of wide acceptance and hence has been used here. S-T depression of 0.5 mm. is designated as "borderline," whereas any depression less than this is not considered significant. For the sake of uniformity these criteria have also been used in describing the records taken after heavy exercise, although S-T depression may sometimes occur after heavy exercise in persons without evident heart disease.[7]

Table I summarizes the findings obtained. After heavy exercise four of the seven subjects demonstrated more severe RS-T depressions in the arctic than in the temperate tests. Also, there were more "abnormal" responses while the men were in the cold shelter than when they were living in the warmer shelter. Multiple premature ventricular contractions were noted after heavy exercise in the Arctic in two subjects living in the cold shelter, whereas these were not observed when they performed the same work while living in the warm arctic shelter or in the temperate zone. One subject showed disappearance of the R wave with formation of a Q wave in V_4 immediately following heavy exercise in the Arctic, but within five minutes the record reverted to the control form.

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*Standard Master tests are performed on steps 9 inches in height, while the steps used in this study were 6 inches high. The clothed weight was utilized in determining the number of trips required.

A Q wave did not develop after the same exercise in a temperate climate. There was no apparent shift of the chest electrode as far as could be determined (Fig. 1).

Only "normal" responses were obtained in both Master tests in temperate climate, whereas two subjects showed "borderline" results in the Arctic after the single Master test and three were "borderline" after the double test. A fourth subject showed an "abnormal" result while in the arctic cold shelter, a "borderline" record while in the warm shelter, and a "normal" response in the

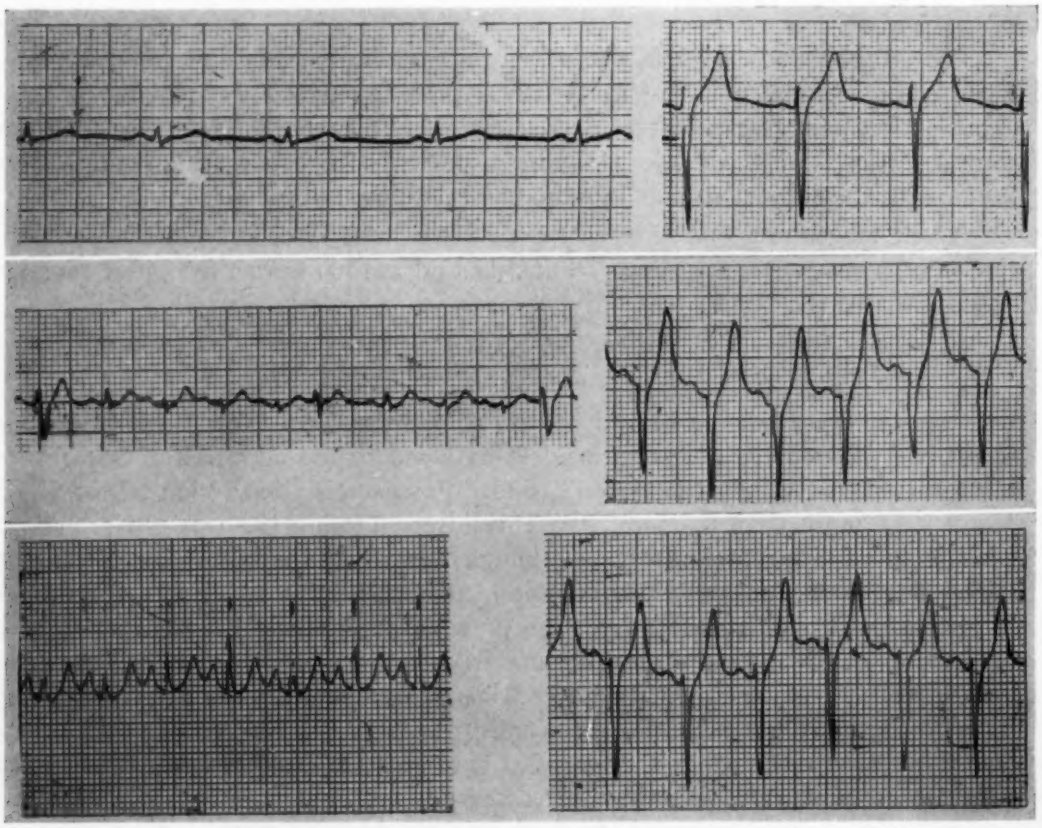

Fig. 1.—Demonstrating some of the changes noted immediately after heavy exercise. (*A*) (Leads I and V_4). Subject standing at rest outdoors in the Arctic. Regular sinus rhythm with no premature beats. R wave in V_4, though slightly diminished in amplitude, is definitely present. (*B*) (Leads I and V_4). Same subject immediately following heavy exercise in the Arctic. Premature beats are apparent in Lead I. In Lead V_4, there is no longer an R wave present, a Q wave now appearing. (*C*) (Leads II and V_4). Same subject after same exercise was performed in temperate climate. No premature beats are evident and the R wave in V_4, though diminished, is present.

temperate climate (Fig. 2). There were more "normal" and fewer "abnormal" Master tests when the men were living in the warm arctic shelter than when they were in the colder shelter.

All the resting records, regardless of the temperature, were normal.

Neither the postexercise P-R interval, heart rate, Q-T_c, or Q-T ratio showed significant changes attributable to shelter temperature or climate (Table II).

The average Q-T:T-Q ratio was higher in the cold shelter records than in the warm shelter electrocardiograms after both heavy exercise and the double Master test. However, whether the differences noted are independent of differences in heart rates and reflect the influence of temperature on the ratio of systole to diastole is not clear. No consistent pattern attributable to climate or shelter temperature could be seen.

Five subjects manifested an increase in voltage and peaking of the T wave after heavy exercise, but each demonstrated this both at arctic and temperate temperatures.

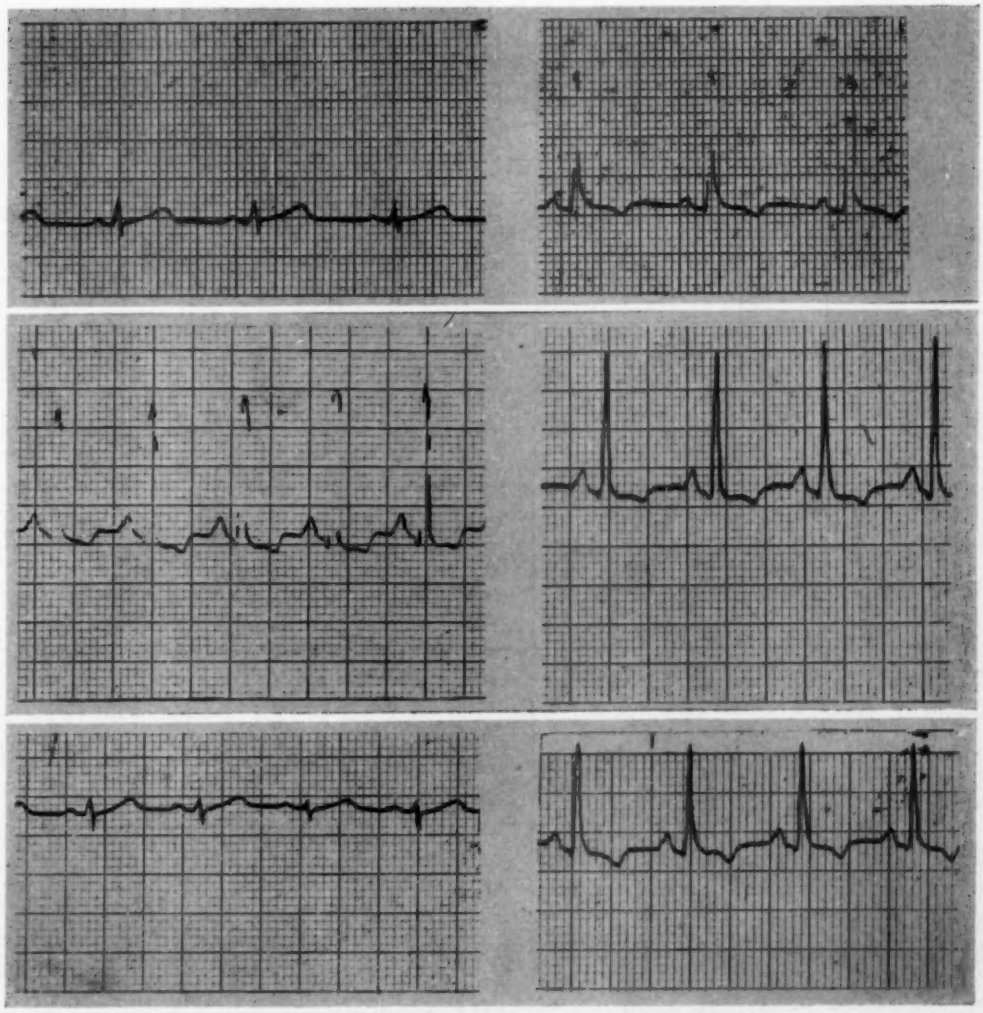

Fig. 2.—Demonstrating changes after performance of the double Master two-step test. (*A*) (Leads I and III). Before exercise, the subject standing outdoors in the Arctic. (*B*) (Lead III). Immediately after outdoor exercise in the Arctic, the same subject living in the colder (50°F.) shelter at this time. S-T depressions of greater than 0.5 mm. are evident. (*C*) (Lead aV_F). Immediately after outdoor exercise in the Arctic, the same subject living in the warmer (70°F.) shelter. S-T depressions of 0.5 mm. are evident. (*D*) (Leads I and III). Same subject immediately after exercise in the temperate zone. No significant S-T segment depression.

TABLE II. MEASUREMENTS OF ECG'S OF NORMAL MALES, HOUSED AT DIFFERENT SHELTER TEMPERATURES, AFTER VARIOUS GRADES OF WORK IN ARCTIC AND TEMPERATE CLIMATES (AVERAGE, MINIMUM, AND MAXIMUM VALUES OF 126 ECG'S ON 7 SUBJECTS).*

TEST	CLIMATE AND SHELTER	R-R (SEC.)	P-R (SEC.)	Q-T (SEC.)	Q-T_c† (SEC.)	Q-T_R‡	Q-T§ / T-Q	TV_4‖ (MM.)
Resting (standing)	Arctic	.69 (.48–.94)	.14 (.12–.16)	.31 (.26–.38)	.37 (.31–.43)	.94 (.83–1.07)	.89 (.57–1.67)	7 (3–12)
	Warm	.70 (.54–.94)	.14 (.12–.16)	.31 (.28–.34)	.37 (.33–.41)	.93 (.83–1.03)	.85 (.57–1.25)	7 (3–10)
	Cold	.67 (.52–.94)	.14 (.12–.16)	.31 (.26–.38)	.37 (.31–.43)	.95 (.88–1.07)	.93 (.68–1.67)	7 (3–12)
	Temperate	.75 (.60–1.16)	.14 (.12–.16)	.33 (.30–.38)	.38 (.35–.41)	.95 (.88–1.03)	.82 (.62–1.14)	7 (2–12)
Resting (supine)	Arctic	.82 (.70–1.04)	.15 (.12–.16)	.32 (.29–.36)	.36 (.34–.39)	.89 (.85–.97)	.66 (.53–.75)	7 (4.5–13.0)
	Warm	.77 (.72–.80)	.14 (.12–.16)	.31 (.29–.32)	.35 (.34–.37)	.87 (.85–.91)	.69 (.63–.75)	6 (5–8)
	Cold	.86 (.70–1.04)	.16 (.14–.16)	.33 (.29–.36)	.36 (.35–.39)	.90 (.86–.97)	.62 (.53–.71)	8 (4.5–13.0)
	Temperate	—	—	—	—	—	—	—
80 steps/min. for 12 min. (4 m.p.h.)	Arctic	.62 (.50–.87)	.14 (.12–.16)	.30 (.28–.34)	.38 (.34–.40)	.96 (.86–1.00)	.97 (.58–1.27)	7 (4–15)
	Warm	.66 (.52–.87)	.14 (.12–.16)	.30 (.28–.34)	.38 (.34–.39)	.95 (.86–1.00)	.93 (.58–1.17)	8 (4–15)
	Cold	.58 (.50–.70)	.14 (.12–.16)	.29 (.28–.30)	.38 (.36–.40)	.96 (.91–1.00)	1.02 (.75–1.27)	7 (4–10)
	Temperate	.55 (.48–.70)	.13 (.12–.14)	.29 (.28–.30)	.40 (.34–.42)	.99 (.85–1.03)	1.18 (.67–1.40)	8 (5–11)

160 steps/min. for 12 min. (8 m.p.h.)	Arctic	.42 (.35–.58)	.13 (.10–.14)	.25 (.24–.28)	.39 (.35–.43)	.98 (.89–1.08)	1.57 (.93–2.18)	10 (3–16)
	Warm	.43 (.36–.58)	.13 (.10–.14)	.25 (.24–.26)	.39 (.37–.43)	.97 (.92–1.08)	1.47 (.93–2.08)	10 (3–13.5)
	Cold	.41 (.35–.46)	.13 (.11–.14)	.25 (.24–.28)	.39 (.35–.42)	.98 (.89–1.04)	1.66 (.96–2.18)	9 (5–16)
	Temperate	.40 (.34–.52)	.12 (.10–.14)	.26 (.22–.30)	.41 (.36–.44)	1.01 (.89–1.12)	1.97 (1.09–2.33)	10 (4–14)
"Single Master test"	Arctic	.59 (.48–.80)	.13 (.12–.14)	.29 (.24–.32)	.38 (.34–.43)	.95 (.83–1.07)	1.06 (.60–1.67)	7 (4.5–10)
	Warm	.57 (.48–.80)	.14 (.12–.14)	.29 (.28–.30)	.37 (.34–.43)	.93 (.83–1.07)	1.11 (.60–1.67)	8 (5.5–10)
	Cold	.61 (.54–.68)	.13 (.12–.14)	.29 (.24–.32)	.38 (.36–.41)	.97 (.91–1.03)	1.00 (.79–1.14)	6 (4.5–8)
	Temperate	.55 (.48–.64)	.13 (.12–.14)	.29 (.28–.32)	.40 (.37–.42)	.99 (.90–1.03)	1.20 (.88–1.40)	6 (3–9)
"Double Master test"	Arctic	.52 (.42–.68)	.14 (.12–.16)	.28 (.24–.32)	.39 (.33–.44)	.99 (.83–1.11)	1.34 (.80–2.00)	7 (3–12)
	Warm	.52 (.42–.58)	.14 (.13–.16)	.28 (.24–.30)	.38 (.33–.40)	.98 (.83–1.08)	1.21 (.80–2.00)	7 (3.5–11)
	Cold	.51 (.46–.68)	.14 (.12–.16)	.28 (.26–.32)	.40 (.36–.44)	.99 (.90–1.11)	1.46 (.89–2.00)	7 (3–12)
	Temperate	.57 (.48–.64)	.14 (.12–.16)	.29 (.28–.32)	.39 (.37–.42)	.97 (.93–1.03)	1.17 (.93–1.56)	6 (2.5–10)

*Minimum and maximum values listed in parentheses. All determinations made in the immediate postexercise records after at least 5 consecutive complexes were measured.

†$Q\text{-}T_c = Q\text{-}T\sqrt{R\text{-}R}$

‡ $\frac{\text{Measured Q-T}}{\text{Ideal Q-T for rate}}$. Ideal Q-T determined by formula ($=0.4\sqrt{R\text{-}R}$).

§ T-Q duration determined by subtracting the Q-T interval from the R-R interval.

‖ Average height of T wave in 5 consecutive complexes.

DISCUSSION

The reaction of the cardiovascular system to cold exposure has been studied in both experimental animals and man. T-wave changes have been produced by drinking iced water[8,9] and by application of ice to the precordium[10] in normal human beings, and by cooling the endocardium or epicardium in dogs.[11] Dermal contact with ice has caused S-T depressions and the precipitation of chest pain in patients with angina pectoris.[12-14] P-R and Q-T prolongation,[15] increase in height of the T wave,[15,16] and premature systoles[17] have been noted in normal men briefly exposed to cold air.

Although the increased number of electrocardiographic abnormalities in the Arctic as compared to a temperate climate is consistent with the results of these investigations, their exact significance is not entirely clear. A study of seven men may represent too small a series to warrant definite conclusions and may not give a valid picture of normal reactions, particularly in view of the high incidence of coronary artery disease in apparently healthy, young American soldiers.[18-20] Inasmuch as the same subjects were used in both the arctic and temperate phases of the study, this factor was controlled to some extent. Nevertheless, even though each subject acted as his own control, intraindividual variability in the electrocardiogram may occur.[21]

The effect of the work itself should be considered in accounting for the observed electrocardiographic changes. Postexercise depression of the RS-T segment,[7,22,23] increase in T-wave voltage,[7,24,25] and premature ventricular contractions[26] have been demonstrated in normal subjects. The work loads imposed by the exercise tests were kept as uniform as possible in the two climates. The same steps were used and clothed weights kept the same. It is felt by some investigators that heavy clothing, if it has a hampering effect on movements, may add to a work load.[27] The arctic clothing worn in this study was loose fitting, without appreciable hampering effect on the movements required. In addition, postexercise heart rates were similar in the arctic and in the temperate climate, suggesting that the work loads for a given test in the two climates were the same.

Despite the variables affecting the electrocardiogram and the relatively few subjects, it would appear that the dual stress of exercise plus cold in the Arctic produces more severe electrocardiographic changes than does the same exercise in a temperate climate. Furthermore, there is indication that living at 50°F. imposes an added burden on the cardiovascular system, although the subjects had no major complaints about the comfort of the 50°F. shelter.

Exactly what factors influence the electrocardiogram during cold exposure are of theoretical and clinical interest. Since the principal change noted in the present study, as well as in other investigations, consists of depression of the RS-T segment, a finding commonly attributed to insufficiency of the coronary arteries to meet the requirements of the myocardium,[1,23,28] attention should be directed to the effect of cold on the coronary arteries. The occurrence of anginal pain upon breathing cold air has been commonly observed[29] and several investigations have shown a higher incidence of myocardial infarction during the winter.[30-32] Gilbert[29] observed a decrease in coronary flow of the dog when the nasal

mucous membrane was stimulated with ice water. This is interesting in that the subjects in the present study, although warmly clad, did have their noses exposed to low temperatures. Berne,[33] however, could find no evidence for reflex coronary constriction on dermal contact with cold.

Although the evidence for reflex coronary constriction upon cold exposure is controversial, it may be that the coronary arteries fail to dilate adequately in response to an increase in cardiac work in the cold-exposed subject. The fact that changes were noted only after exercise would support the supposition that it is failure of coronary dilatation rather than reflex vasoconstriction which is responsible for the alterations observed after exercise in the cold. That organic disease of the coronary arteries may be a factor in these apparently healthy subjects is suggested by the finding of anatomical evidence of coronary artery disease in 77 per cent of young, American soldiers killed in action, none of whom had had manifestations of cardiovascular disease.[18]

Alterations in the demands of the body for oxygen in the cold may also be of significance. The principal changes observed in the arctic electrocardiograms are similar to those found with hypoxemia.[28,34] The subjects studied here showed that their oxygen needs for the same work were about 12 per cent higher in the Arctic than in the temperate zone.[35] Whether the increased energy cost of exercise in the Arctic is associated with an early development of myocardial hypoxia provides interesting speculation, although there is no definitive evidence to support this supposition at present.

The influence of cold on hormones and electrolyte equilibrium should also be considered. Discharge of epinephrine and an increase in corticoid content of the blood have been noted in cold-exposed rats.[36] Adrenal gland secretions have caused alterations in the electrocardiograms of experimental animals and man, with P-R prolongation, S-T depression, premature systoles, and changes in the T wave being reported.[37-40]

Although cold exposure definitely influences the cardiovascular system, no untoward effects were noted until the men were subjected to exercise, at which time changes in the electrocardiogram acted as a clue to failure of complete cardiovascular adaptation to stressful conditions in the cold.

SUMMARY

The effects of arctic climate and different shelter temperatures on the electrocardiogram were investigated in seven normal young men performing standard work outdoors in arctic and temperate climates.

Significant electrocardiographic changes occurred with greater frequency and severity in the arctic than in a temperate climate after both heavy and light work. In addition, there were more severe changes when the men lived in a 50°F. arctic shelter than when they were housed at 70°F.

There were no abnormalities in the resting electrocardiograms. Depression of the RS-T segment, increase in height of the T wave, premature ventricular contractions, and disappearance of the R wave in V_4 were the principal post-exercise alterations observed.

The increased incidence of significant changes noted in the Arctic and when the men lived in the cold shelter suggests that the dual stress of exercise plus cold exposure affects the electrocardiogram to a greater extent than exercise alone. The effects of cold exposure on the coronary arteries, adrenal gland secretions, and oxygen needs of the body are discussed in light of the observed electrocardiographic alterations.

SUMMARIO IN INTERLINGUA

Esseva investigate le effectos del climate e de differente temperaturas de allogiamento super le electrocardiogramma de normal juvene adultos mascule ingagiate in varie grados de labor in plen aere sub conditiones arctic e de climate temperate. Exercitio in le arctico resultava in plus sever alterationes electrocardiographic que le mesme exercitio in climate temperate, e plus sever alterationes esseva etiam notate quando le subjectos habitava un plus frigide refugio arctic que quando illes esseva installate in habitationes de temperaturas confortabile. In le lumine del observate alterationes electrocardiographic nos discute le influentia de exposition a frigido super le arterias coronari, le secretiones del glandulas adrenal, e le requirimentos de oxygeno del corpore.

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FOUR CASES OF "BENIGN" LEFT BUNDLE BRANCH BLOCK IN THE SAME FAMILY

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IT IS the purpose of this communication to present four instances of apparently benign left bundle branch block which were observed in two generations of one family of thirteen living members. To our knowledge such an occurrance in a family has not been reported previously.

Bundle branch block has long been interpreted as indicating serious heart disease, usually disease of the coronary arteries. Of the two major varieties, right bundle branch block has a statistically better prognosis than left. That bundle branch block is not universally associated with a poor prognosis is demonstrated by the studies of a number of authors.[1-3] More recently Vazifdar and Levine[4] reported a series of 452 cases of bundle branch block collected from an ambulatory practice over a twenty-nine-year period. In this large group were thirty-one instances of bundle branch block without apparent organic heart disease. These were referred to as "benign." Of these thirty-one "benign" cases, four were of the left bundle branch block variety.

Likewise, Wolfram[5] reported fifty-two cases of bundle branch block of which seven were of the "benign" left bundle branch block variety. These were from a study of 5,000 tracings taken in an outpatient cardiac clinic of a large veterans' facility. Using Wolfram's statistics, it appears that bundle branch block occurs in approximately 1 per cent of persons seen in an ambulatory cardiac diagnostic clinic, and the benign form of left bundle branch block in one of 700 such persons.

MATERIAL

The study was suggested by the chance opportunity afforded the author to treat on separate occasions two members of a family for symptoms unrelated to the heart. As part of the routine evaluation electrocardiograms were obtained on each, and both showed left bundle branch block. Subsequently electrocardiograms were procured on the remaining six members of the immediate family and the six siblings of the mother. There were no living paternal relatives. Of the fourteen persons studied electrocardiographically, four demonstrated left bundle branch block. As shown in Fig. 1, these occurred in the mother, two of

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her children, and her oldest brother. From these four, detailed medical histories and cardiovascular examinations were obtained and these will be briefly presented.

CASE REPORTS

CASE 1.—A.S.: A 68-year-old woman was studied extensively during a two-week hospitalization in 1953 for symptoms including dry hacking cough, daily fever, fatigability, generalized muscular pain, and anorexia. These followed, and had been present since a transcient, generalized, pruritic, contact dermatitis one and one-half months prior to being seen. The only serious past illness was scarlet fever, with which she and several of her children were sick several weeks in 1930. There was no known complication. Her father had died in middle age of pneumonia; her mother died, presumably of a heart attack, at 84. There was no history of myocardial failure or angina pectoris.

Physical Examination.—Blood pressure, 140/75 mm. Hg; pulse, 80. She appeared tired, pale, chronically ill, and evidenced weight loss. The heart was not enlarged, and no murmurs or abnormal chest findings were noted on repeated examinations. She had an intermittent fever reaching 101° to 102° F. each afternoon during her stay.

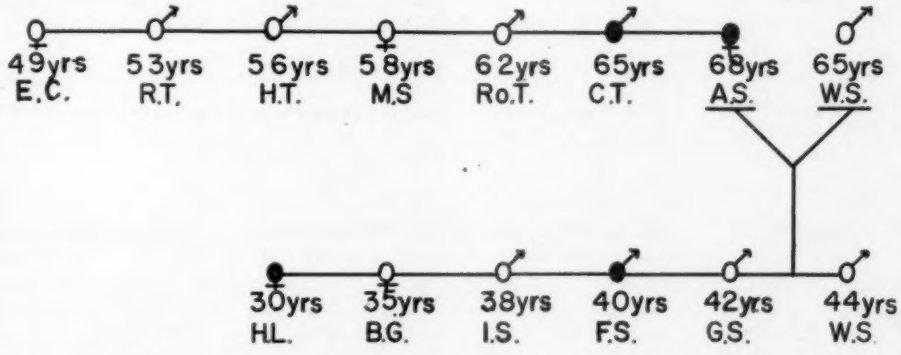

Fig. 1.—Family tree of persons included in the study. Sex indicated by symbol, under which is the individual's age. Solid symbols indicate persons with left bundle branch block.

Laboratory Data.—Hemoglobin, 8.2 Gm. per cent; sedimentation rate 117 mm. per hour Westergren; R.B.C. 2,950,000; W.B.C. 10,000 with normal differential count. Throat, sputum, bone marrow, and multiple blood cultures were negative for pathogens. Agglutinins for typhoid, Brucella, and paratyphoid organisms were not present in the serum. X-ray studies of the stomach, colon, heart, and chest were normal. The gall bladder was large, lobulated, and poorly visualized, but no calculi were seen. Marrow obtained by aspiration showed decreased cellularity, especially of the red cell series. The electrocardiogram (Fig. 2,*A*) revealed complete left bundle branch block of discordant variety, with left axis deviation. The position was semihorizontal.

Course.—Following the cited studies, which failed to explain her symptoms adequately, she was given 1,000 c.c. blood. She had a brief febrile reaction during the transfusion, but subsequently felt better. One month later, repeated studies of her bone marrow were normal and the majority of her symptoms had subsided. One year after discharge she was entirely well and active. Her electrocardiogram had not changed.

Comment.—The nature of this patient's illness was obscure but seemed to be most consistent with a hypersensitivity state. There was no clear relationship between her presenting illness and the conduction defect. A reflex arrhythmia from the gall bladder seemed unlikely.

CASE 2.—H.L., daughter of Patient 1: This person was studied extensively in June, 1953, at the age of 29 years, for multiple symptoms in a number of systems. Among her symptoms was "difficult breathing," usually at rest, which was more a dissatisfaction with a given breath followed by a deep, sighing respiration, than true dyspnea. She also experienced intermittent, sharp, jabbing, left axillary pains, especially when working with her arms. These she ascribed

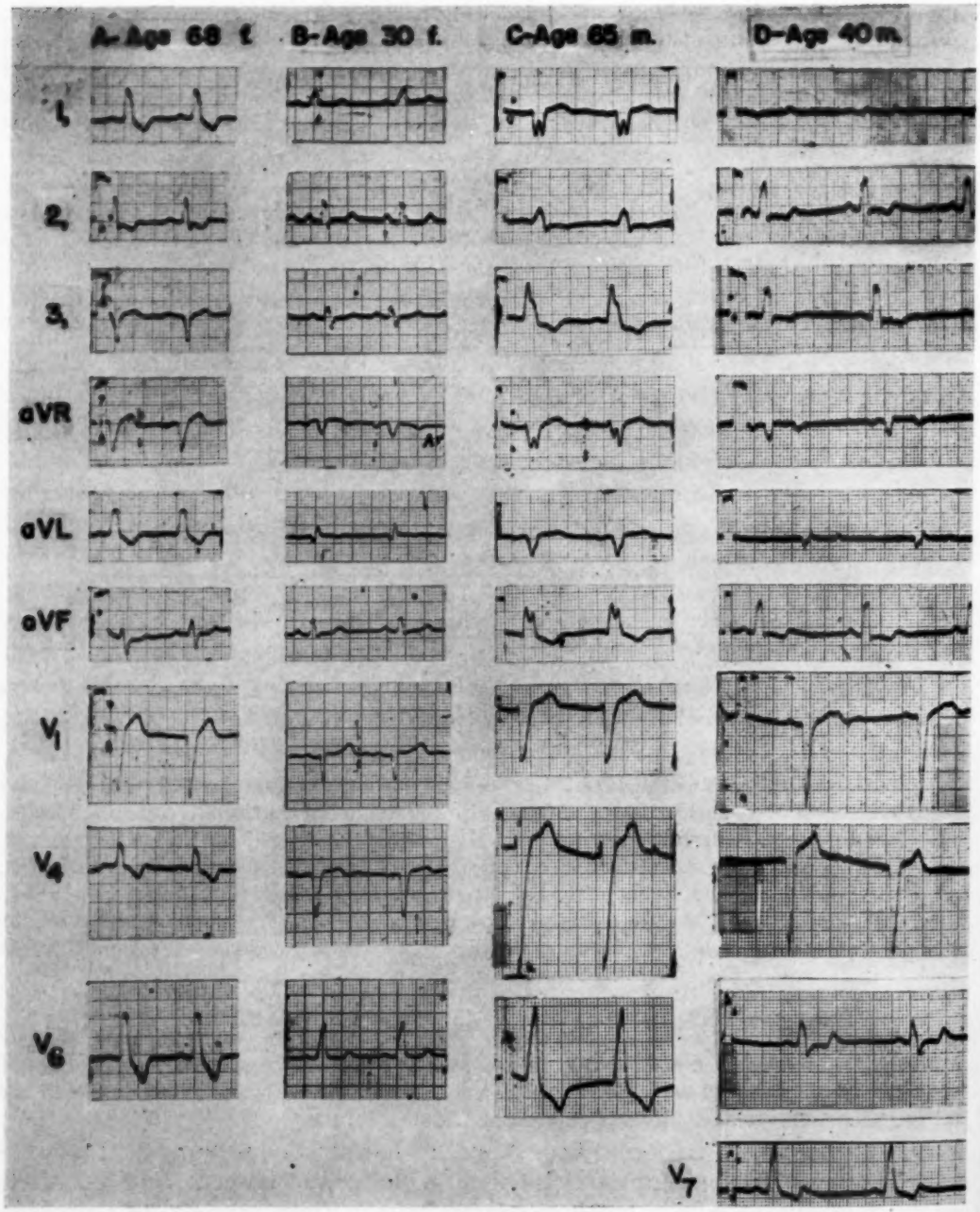

Fig. 2.—Electrocardiograms from persons demonstrating left bundle branch block. (See text for discussion.) No. V_1, of Case *C*, is obtained at 1/3 normal sensitivity.

to her heart. Her numerous other symptoms were not pertinent other than to strengthen the opinion that her complaints were largely psychogenic in origin. In 1930 she, also, was ill with scarlet fever.

Physical Examination.—Blood pressure, 108/80; pulse, 70. She was extremely emotional, dwelling on her heart, sighing deeply, and was on the verge of tears almost continuously. Tonsils and regional nodes were slightly enlarged but without evident infection. The chest was entirely negative and the heart was clinically normal, except for a split second sound in expiration at the base. There was slight vasospasm in the hands and feet.

Laboratory Data.—The chest film showed "slight straightening of the left cardiac border and prominence in the region of the pulmonary artery." Urinalysis, complete blood count, sedimentation rate, and fasting blood sugar were normal. The electrocardiogram (Fig. 2,*B*) revealed complete left bundle branch block of concordant type (electrical axis, +30; the position, semivertical with clockwise rotation). A modified Master's test to physical tolerance showed no change in QRS, S-T segment, or T wave after four minutes.

Course.—She was treated with reassurance and mild sedation with gratifying improvement. The family reported that she has been active and asymptomatic in the eighteen months since she was seen.

Comment.—The type of left bundle branch block in this patient was quite different from that in the first case, probably due to the electrical position and rotation of the heart.

CASE 3.—C.T., brother of Patient 1: This man was a 65-year-old farm laborer who had lived a stringent existence. He was examined in November, 1954, as part of the complete study of this family. His nutrition was poor and standard of living at a minimum. Nonetheless, his only spontaneous complaint was gradually failing vision over a two-year period. He gave no indication on detailed questioning of coronary or myocardial insufficiency, and his exertional tolerance, as judged by the nature of his work, was excellent. He admitted to no serious illness, operation, or hospitalization.

Physical Examination.—Blood pressure, 170/100 mm. Hg; pulse, 74. He was a seedy, worn, undernourished, elderly-appearing man. There were early cataracts bilaterally. His remaining teeth were poor. His chest showed slightly diminished breath sounds, increased resonance, and an occasional coarse rhonchus bilaterally. His heart was not clinically enlarged. A Grade 1 apical, systolic, blowing murmur was heard and the second sound at the base was split in expiration. The remainder of the examination was not remarkable. The electrocardiogram (Fig. 2,*C*) revealed complete left bundle branch block of discordant variety, with marked right axis deviation (+125). The position was vertical with extreme clockwise rotation. The S-T segments from areas reflecting right ventricle cavity were elevated with upright T waves. Those reflecting left ventricle were depressed with inverted T waves.

Comment.—In spite of the absence of evidence of organic heart disease from the history and physical examination, the electrocardiogram in this case was suggestive of diffuse myocardial damage and left ventricular hypertrophy.

CASE 4.—F.S. son of Patient 1: This man, a 40-year-old laborer in a tannery, was examined in November, 1954, at our request. He had never been seriously ill or hospitalized in his entire life. His work was physically arduous but had never caused him any symptoms. He had an occasional, indurated, erythematous, tender dermatitis, which was secondary to substances contacted in his work.

Physical Examination.—Blood pressure, 135/80; pulse, 58. He was a robust, lean, muscular individual. The chest was entirely normal. Heart was not clinically enlarged and there were no murmurs. The basal second sound was audibly split in expiration. There were no other

pertinent findings. The electrocardiogram (Fig. 2,*D*) showed complete left bundle branch block with right axis deviation. The position was vertical and there was marked clockwise rotation. S-T segments in leads reflecting the left ventricle were slightly depressed and the T waves were diphasic. This tracing was consistent with a complete left bundle branch block of the concordant variety.

Comment.—The electrocardiogram in this case was very similar to that of Case 2. The concordant pattern was again due perhaps to the position and rotation of the heart.

DISCUSSION

We report these cases realizing that the brevity of our follow-up makes it hazardous to be dogmatic about the benign nature of the left bundle branch block. In Case 3, the elevation of blood pressure and the breadth and amplitude of the depolarizing and repolarizing potentials of the cardiogram lend serious doubt as to the benignity of the bundle branch block in this individual. In the remainder of the cases there was no indication in any of the studies of organic heart disease.

The etiology and duration of the benign conduction abnormalities appearing on routine electrocardiographic tracings are usually unknown. Many undoubtedly have been present for years, and a few perhaps since birth. However, we find no reports of left bundle branch block occurring in infants without associated congenital heart disease. One theory of origin proposes that they are secondary to otherwise innocuous infections by a variety of organisms.[6-10] Scarlet fever has been reported as the cause of transient A-V block,[11] and in this regard it should be emphasized that two (patients 1 and 2) of the four presented had the disease twenty-three years prior to study.* Another member of the family (W.S., Fig. 1) was evaluated in 1949 for pericardial calcification manifest by a friction rub. He also had had scarlet fever in 1930. His tuberculin and Wassermann tests were negative, but a brucellergen skin test was positive. He had no disability and his electrocardiogram has always been normal. There seems then to be circumstantial evidence to implicate infection in the benign cardiac abnormalities of this family.

Right axis deviation, as in the electrocardiograms of patients 3 and 4, is unusual in the presence of left bundle branch block. It is likely that these cases would have been interpreted as right bundle branch block prior to the advent of precordial leads. The appearance of right axis deviation with left bundle branch block is due to the extreme vertical position and marked clockwise rotation of the heart as demonstrated by Foster in his studies with dogs.[12] The vertical position and rotation of the heart as determined by the augmented and precordial leads is apparently a familial characteristic, being present in ten of the fourteen tracings included in this study. It is most probably an inherited trait which, when coupled with the high incidence of left bundle branch block, suggests the concept of a familial susceptibility of the left bundle of His to injury. This susceptibility may be due to an inherited deficiency of blood vessels to the septum,

*Patients 3 and 4 were aged 41 and 16, respectively, in 1930, when Patients 1 and 2 had scarlet fever at the ages of 44 and 5 years, respectively.

which is aggravated by the arteritis of streptococcal infections[13-15] (Cases 1 and 2) or demands of ventricular enlargement (Case 3) leading to permanent damage to the bundle of His and, consequently, to left bundle branch block. This is clearly speculation, but nonetheless there does appear to be, in the population in general and this family in particular, a number of otherwise well persons who are predisposed to develop bundle branch block from a wide variety of ordinarily subliminal stresses. These individuals with "benign" bundle branch block form a group whose recognition is increasingly common.

SUMMARY AND CONCLUSIONS

We have presented four instances of left bundle branch block in the same family. In three there was no clinical evidence of organic heart disease. In one, hypertension was present and the electrocardiogram was suggestive of left ventricular myocardial damage.

Right axis deviation was associated with left bundle branch block in two cases. This was thought due to the vertical position and clockwise rotation of the heart. This position was observed in ten of fourteen tracings in the study and was felt to represent a familial trait. This trait, plus the high incidence of associated left bundle branch block, suggested a familial susceptibility of the bundle of His to injury. It is postulated that this susceptibility is due to inherited deficiency of the septal blood supply.

SUMMARIO IN INTERLINGUA

Nos presenta quatro casos de bloco de branca sinistre in le mesme familia. In tres casos il habeva nulle indication clinic de organic morbo cardiac. In un caso il habeva hypertension, e le electrocardiogramma simulava myocardiac lesiones sinistro-ventricular.

In duo casos deviation dextrorse del axe esseva associate con le bloco de branca sinistre. Isto esseva explicate per le position vertical e le rotation dextrorse del corde. Iste position esseva observate in dece ex dece-quatro registrationes in le curso del studio. Illo esseva interpretate como un tracto familial. Iste tracto, viste insimul con le alte frequentia de bloco de branca sinistre associate con illo, pare indicar un alte susceptibilitate familial a lesiones del fasce de His. Nos postula que iste susceptibilitate resulta de un carentia hereditari del apporto sanguinee del septo.

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LOCATION OF THE ELECTRICAL CENTER OF VENTRICULAR DEPOLARIZATION

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LOCATING the electrical center of ventricular depolarization is basic for progress in electrocardiography. It is useful for accurate determination of the range of electrical heart center locations, lead axes, heart vectors, body homogeneity, and the relationship between thoracic anatomy and heart electrical activity.

Frank[1,2] has developed a mirror pattern cancellation technique which precisely locates this center. This technique geometrically fits data obtained by cancellation of mirror patterns in the human subject to a transverse locus* of the electrical image surface of a three-dimensional human torso model.[3] Since each transverse image locus, representing the distribution of potential on the model surface, results from a particular dipole location, the closest fit of human cancellation data to a specific image locus defines an electrical heart center in the subject equivalent to a dipole location in the model.

It is the purpose of this paper to present our experience with this technique and report equivalent dipole locations in seven subjects. Results indicate that body surface potentials, including precordial, may be considered with good approximation to originate from a dipole source and that the body is very nearly a homogeneous conducting medium. The various equivalent dipole locations corresponded closely with the location determined in a normal individual by Frank.

METHOD

Seven men, six normal and one with mild hypertensive heart disease, with various thoracic configurations were studied. From four to six cancellations were determined in each individual during two to five two-hour sessions. The principles and technique underlying this method have been described in detail elsewhere.[1] (See Fig. 1,*A* for the electrical circuit.)

First a determination of the transverse anatomic level, which approximates the electrical heart center level, is carried out in each subject. This is done by estimating radiologically, in quiet respiration, the level of the center of the ventricular mass. It is important to take into account that portion of the heart

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*The transverse image locus dealt with in this paper is the line in image space that corresponds to the anatomic line around the chest at the transverse level of the electrical heart center.

shadow which extends below the level of the diaphragm. The subject is then aligned in a board cut out to fit the thorax and radially marked at 22½ degree intervals, labeled *A* to *P*, to identify corresponding anatomic and image surface

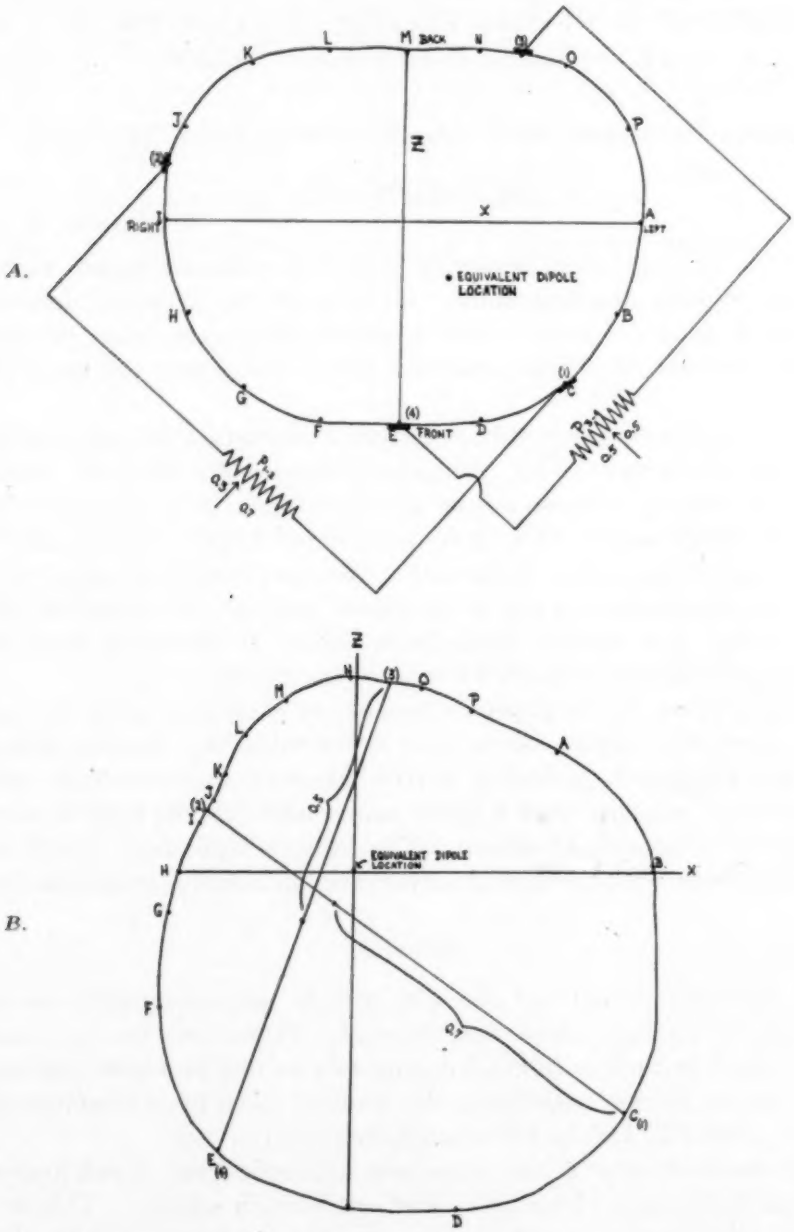

Fig. 1.—*A*, The anatomic electrode arrangement for one cancellation (subject W.A.). Electrodes *1*, *2*, and *4* are fixed at *C*, halfway between *I* and *J*, and *E*, respectively. Electrode *3* is halfway between *N* and *O*. Potentiometer 1-2 was set at 0.7 and potentiometer 3-4 at 0.5. *B*, The corresponding geometric representation in image space. The electrode positions are connected by lines. The dots represent the locations of the sliding taps of the potentiometers.

points. Points *E* and *M* are in the midline, front and back, and *A* and *I* in the midline laterally, left and right. The board is positioned at waist level and by means of a vertical caliper, electrode placement is always made at heart center level. The location of this level with relation to a fixed anatomic surface point (such as the left nipple) is noted, enabling duplication for future work on any subject. Verification of correctness of level estimate is by trial and error cancellation. If cancellation is obtained with the search electrode too high, the other three electrodes are too low, and vice versa, and all must be adjusted accordingly. When all electrodes are at proper level, satisfactory cancellation will be obtained within ±2 inches of the heart center level.

Location of mirror patterns is facilitated by image surface orientation. Reference is made to the image locus for a typical dipole location (image locus 22 shown in Fig. 1,*B*). Any two points on the image locus are selected so the line joining them in image space passes through the vicinity of the dipole. Then two electrodes (*1* and *2*) are placed at corresponding anatomic points to serve as the reference system. A typical choice would be *1* at *D* and *2* at *N*. The setting of the potentiometer between these electrodes (potentiometer 1-2) is determined by locating the sliding tap in image space near the dipole on the line joining image points of electrodes *1* and *2*. In terms of distance from image location of electrode *1*, this was typically 60 per cent of the total distance between image points of electrodes *1* and *2*. The potentiometers being calibrated from 0 to 1.0, the setting of potentiometer 1-2 would be 0.6. This reference system is usually fixed throughout the study of any one subject, but may be changed if the image locus for a subject appears to be quite different from the typical one used for orientation.

The choice of reference electrodes to permit potentiometer settings near the dipole center is made so that the electrode locations for cancellations will be reasonably distributed around the chest. For each cancellation two additional points on the image locus are selected, so that the line joining them goes approximately through the image point representing the sliding tap of potentiometer 1-2. Two additional electrodes (*3* and *4*) constituting the exploring electrodes, are appropriately placed anatomically. Typical pairs of such points might be *C* and *K*, *G* and *B*, etc. Since locations of electrodes *1*, *2*, and *4* and setting of potentiometer 1-2 are fixed, cancellation may be obtained by systematically varying location of search electrode *3* and the setting of the potentiometer between electrodes *3* and *4*. The residual potential between the sliding taps of the two potentiometers is then recorded. Additional residual potentials are then studied for points adjacent to the final location of search electrode *3* to confirm the fact that the best cancellation was obtained.

The degree of cancellation is determined by the formula,[4]

$$C = \frac{r}{(1 - n)\, V_3 + n\, V_4} 100,$$

where n is the fractional potentiometer 3-4 setting, and V_3 and V_4 are the peak-to-peak potentials recorded by electrodes *3* and *4* with respect to potentiometer 1-2 reference, and r is the peak-to-peak residual cancellation potential with potenti-

ometer 3-4 set at n. A satisfactory cancellation coefficient is less than 15 per cent, with residual potential preferably 50 to 80 microvolts.

Finally the combinations of electrode locations and potentiometer setting for cancellations in a subject are geometrically plotted on various transverse image loci. The image locus yielding the smallest cluster of points representing potentiometer settings determines the equivalent dipole location for the subject.[1] Where the smallest cluster is difficult to determine by inspection, or where two different reference potentials have been used in one subject, the proper image locus may be determined by measuring separately for each reference potential the distance between image points representing potentiometer settings, and squaring these. The smallest total indicates the proper image locus.

POINTS OF TECHNIQUE

It is essential to minimize controllable sources of error. The most important of these are: respiratory movement of the heart, positional change of the subject, inaccurate placement of electrodes, contiguity of electrode jelly, and failure to minimize skin resistance. Ideally, cancellation should be determined in a constant phase of respiration. We did not do this, but recorded mirror patterns and residual potential for each cancellation over a sufficient period to include respiratory variation. In determining cancellation coefficients the smallest peak-to-peak potential of mirror patterns and residual potential were selected. Effort was made to maintain the subject's position or realign as necessary. Fatigue caused two problems: change in the subject's alignment and, by the end of one and one-half to two hours, muscle tremor sufficient to obscure the record when residual potential was recorded at high amplification. Contiguity of jelly was avoided by wiping dry for determinations at closely adjacent points. The skin resistance at each electrode site was determined before recording. A D.C. resistance of 5 to 10,000 ohms, small compared to the 100,000 ohm resistance of the potentiometers, was considered satisfactory.

Several practical difficulties were encountered. In one individual (R.S.), mirror patterns in certain locations, showing unusual splintering, were difficult to reproduce despite prolonged search, and when similar patterns were found cancellation was poor. Lack of better cancellation in this subject in these locations may have been due to lack of precise enough search. It is possible that use of needle electrodes would have produced better results. Our electrodes were thin discs, 1.5 cm. in diameter. In this same individual excellent cancellations were determined in other locations and enabled location of the equivalent dipole.

In the vicinity of the transitional zone, where changes of electrode location in relation to dipole location are very critical of changes in amplitude and phasing, it is impractical to find mirror images with the present technique. This problem may be offset by determining the location of the transitional zone at heart center level and placing the reference potential system (electrodes *1* and *2*) in this zone. This leaves free all other nontransitional pairs of points for mirror image determination. In another individual (W.A.), with a vertical QRS axis, whose transitional zone crossed the anterior chest in two places and was rather

broad, readily obtainable cancellations were limited to the precordial and corresponding back area. This may have decreased the accuracy in determining the equivalent dipole location in this subject.

RESULTS

In our series of determinations cancellation coefficients ranged from 3 to 15 per cent, averaging 8 per cent. The cancellation coefficients are summarized in Table I.

Equivalent dipole locations of ventricular depolarization in seven subjects were as follows: four at location *22*, and one each at locations *13*, *31*, and *32*. These are illustrated in Fig. 2, which represents the transverse anatomic plane

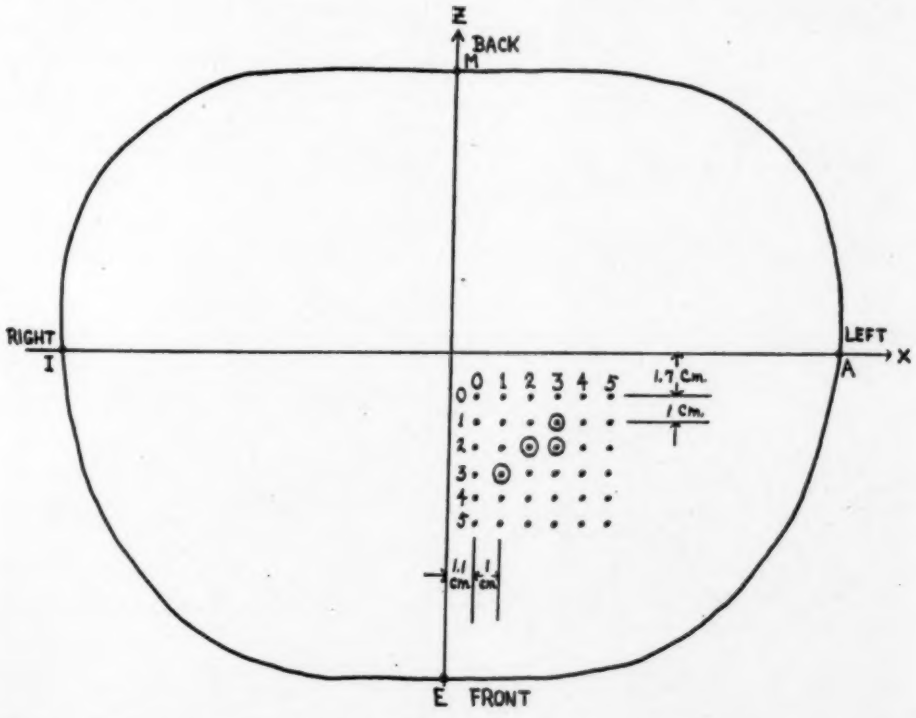

Fig. 2.—The anatomic equivalent dipole locations for seven subjects within the heart area. These are shown on an exact diagram derived from a torso model.[1] In this diagram the dipole locations would be enclosed by an area measuring 2 by 2 cm. It should be noted that the distance of the locations from each other and from the transverse and anteroposterior axes would be different if one utilized a thoracic diagram proportional to the actual measurements of each subject, but this difference is small. (See text for further explanation.) Four locations were at position *22*; one each at positions *13*, *31*, and *32*.

of the torso model in which the seventy-one dipole locations were studied.[1,3] Each point in the anatomic heart area represents a dipole location. They are spaced 1.0 cm. apart and at a distance from the transverse and anteroposterior axes as indicated. The locations are identified by combining numbers in the transverse axis with those in the anteroposterior, i.e., 01, 22, 35, etc. Applied to this particular anatomic plane the equivalent dipole locations in our subjects

may be enclosed by a square 2 by 2 cm. More refined location of the equivalent dipoles would necessitate determining the distance of each dipole location from the transverse and anteroposterior axes in terms of the ratio of the thoracic measurements of each subject to those of the torso model, which were 25 by 33 cm.

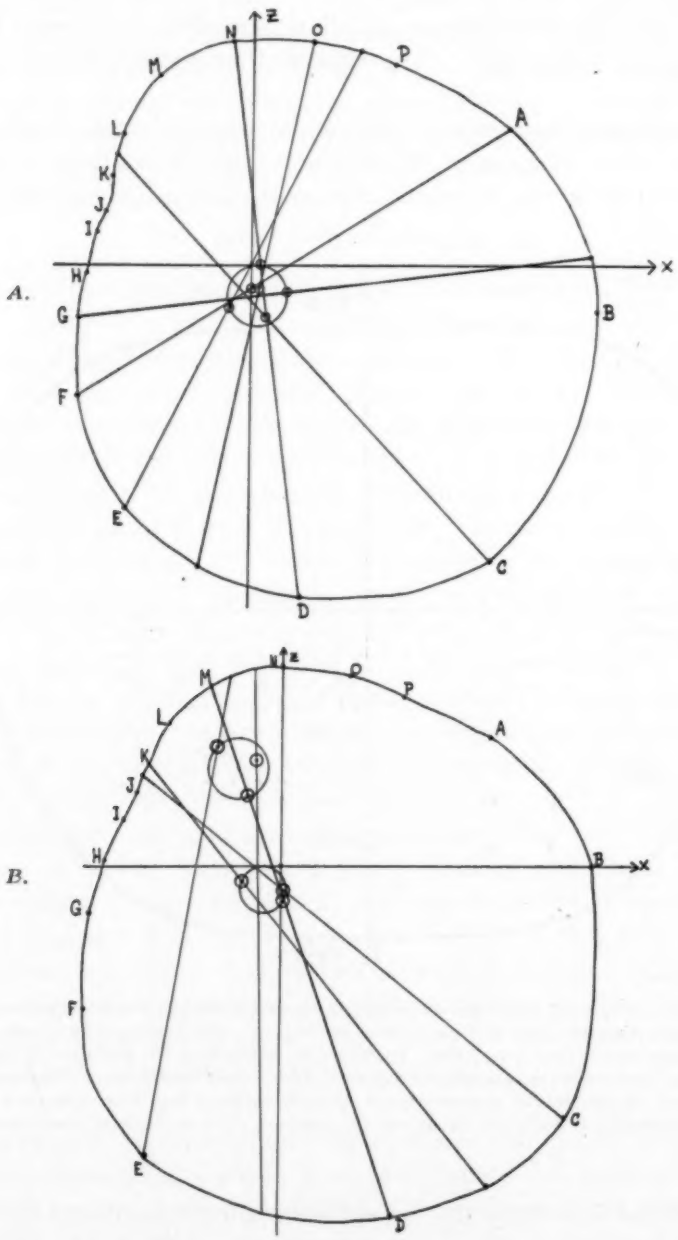

Fig. 3.—The transverse image locus with its equivalent dipole location in two subjects is shown. In one subject (*A*) reference electrodes 1 and 2 and the setting of potentiometer 1-2 were maintained the same throughout the experiment. In the second subject (*B*) the position of electrodes 1 and 2 was unchanged. However, the setting of potentiometer 1-2 was modified. Lines connect each electrode location. The dots indicate the potentiometer settings. The cluster of dots is encircled. There is a separate cluster for each reference system.

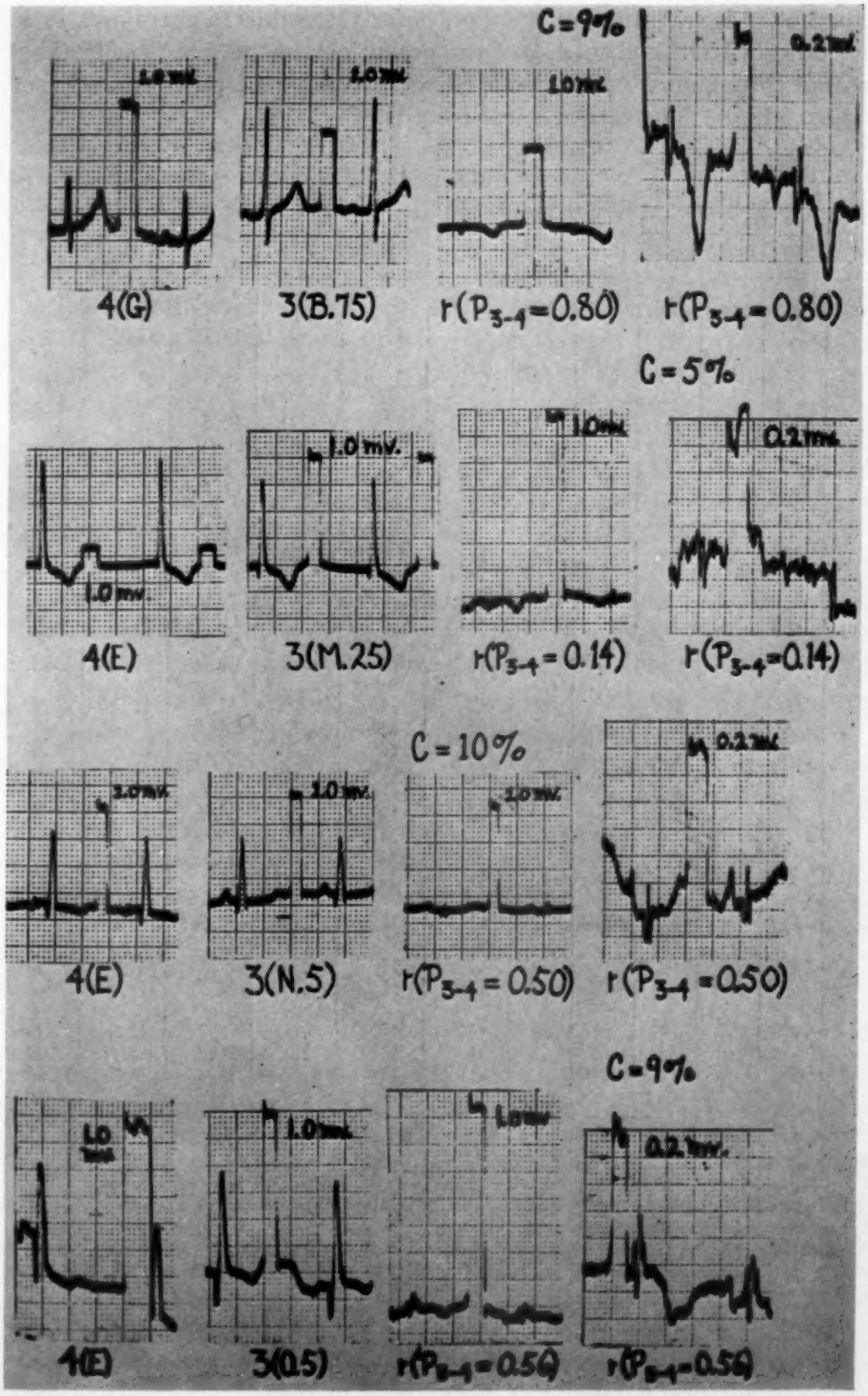

Fig. 4.—From left to right are shown the mirror patterns recorded by electrodes *4* and *3* at the designated locations: the residual voltage (*r*), with standardizations of 1.0 and 0.2 mv., respectively. P_{3-4} refers to the potentiometer connecting electrodes *3* and *4* and indicates the setting of the potentiometer. The Cancellation Coefficient is indicated above each set of records. Polarity of electrode *4* potentials is inverted for convenience in comparing wave shapes.

The image loci containing the dipoles for two subjects are shown in Fig. 3. In one subject (J.D.) one setting of the potentiometer between electrodes *1* and *2* was used throughout; in the other (R.S.) two different potentiometer settings were used. Fig. 4 illustrates typical records.

TABLE I

SUBJECT	AGE	HGT.	WGT.	H.O.	D.L.	E_1	E_2	P_{1-2}	E_3	E_4	P_{3-4}	C.C.
J.M.	37	71	195	I	32	C.5	L	.60	P.5	E	.50	10
						C.5	L	.60	B.75	G	.80	9
						C.5	L	.60	M.5	D	.34	12
						C.5	L	.60	A.5	F	.70	11
J.D.	59	67	177	H	31	D	N	.60	K.5	C	.40	7
						D	N	.60	A	F	.60	8
						D	N	.60	O	D.5	.47	6
						D	N	.60	O.5	E	.56	9
						D	N	.60	A.75	G	.59	9
H.H.	30	69	146	I	13	D	O	.75	K.5	C	.30	3
						D	O	.75	P.5	E	.13	5
						D	O	.75	A	F	.22	3
						D	O	.75	H.5	B	.39	7
						D	L.5	.75	P.25	F	.30	7
						D	L.5	.75	O.75	F	.24	5
W.A.	50	67	167	V	22	C	I.5	.70	N.5	E	.50	10
						C	I.5	.70	M.5	D.75	.34	11
						C	I.5	.70	K	C.5	.28	7
						C	I.5	.70	N	D.5	.33	14
R.S.	20	75	165	V	22	D	M	.80	M.6	D.5	.16	3
						D	M	.80	M.25	E	.14	5
						D	M	.60	J.5	C	.33	10
						D	M	.60	K	C.5	.27	9
H.S.	51	72	175	I	22	C	H	.50	A.5	E	.53	6
						C	H	.50	E.25	B	.32	12
						C	H	.75	P.5	E.5	.70	12
						C	H	.75	M.8	D.5	.39	12
R.B.	47	67	191	H	22	C	K	.60	O.3	E.5	.35	15
						B	F	.50	K.5	C	.60	8
						B	F	.50	N	D	.53	11
						B	F	.50	A	E	.40	11

Height of each subject is indicated in inches and weight in pounds.

H.O. indicates heart orientation: I = intermediate; V = vertical; H = horizontal.

D.L. indicates equivalent dipole location in the human torso model for each subject. E_1, E_2, E_3, and E_4 are electrode positions for the cancellations.

P_{1-2} and P_{3-4} refer to the potentiometers connecting electrodes 1 and 2, and 3 and 4, respectively.

C.C. is cancellation coefficient in per cent.

DISCUSSION

The cancellation technique of Frank used in these experiments proved to be a precise and practical research method. The existence of nearly exact mirror patterns as proved by cancellation supports the hypothesis that the heart acts approximately as a dipole. The excellent degree of cancellation obtainable is

evidence, as well, for the precision of the technique, and agrees favorably with the degree of cancellation determined by Frank.[1,2] Limitation of cancellation to approximately 90 per cent is due mainly to a combination of errors in technique and slight limitation of heart dipolarity.

Close geometric approximation of human cancellation data, and data from an exact human torso model suggest that there is remarkable correlation between heart electrical activity and ideal conditions in the model. Results so far would indicate that the combined error due to heart nondipolarity and body inhomogeneity is within ±15 per cent.

The effect of thoracic contour on surface potentials has been found to be negligible at the transverse level containing the dipole.[1] This fact is supported by close anatomic grouping of equivalent dipole locations in seven subjects of different thoracic configurations. Although thoracic contour is not critical in determining surface potentials, it should be emphasized that dipole eccentricity is extremely critical in such determination. The fact that in four individuals with different anatomic heart orientation equivalent dipole locations were similar, suggests that heart size and shape, at least those within normal limits, do not necessarily have much effect upon the equivalent heart dipole location. That the anatomic level selected by x-ray as the level of the center of the ventricular mass was usually satisfactory for good cancellations, suggests that the anatomic and electrical heart centers may be close, at least in the head-to-foot direction.

The method offers several research possibilities. One is a quantitative means for more accurate determination of the magnitude and direction of lead vectors for vectorcardiography. So far the chief disagreement has concerned the selection of appropriate leads and standardization factors for each lead. The solution of this problem appears to be closer at hand. As noted by Frank[1] and Schmitt and associates,[4] we also observed that the centers for auricular depolarization and ventricular repolarization probably differ in location from that for ventricular depolarization, as evidenced by the fact that in instances where QRS cancellation was excellent, P and T waves did not cancel.

SUMMARY

Six normal men and one abnormal man with various thoracic configurations were studied by a precise mirror pattern cancellation technique. Four to six mirror pattern cancellations were determined in each subject. These data were compared geometrically with those obtained from a three-dimensional model of the human torso, and the equivalent heart dipole location in each subject was determined. The method was found practical as a research technique and not excessively time-consuming. The technique is discussed briefly and results presented which indicate that the electrical center for ventricular depolarization was close to the estimated anatomic center of the ventricles in our subjects.

SUMMARIO IN INTERLINGUA

Sex normal e un anormal homines con varie configurationes thoracic esseva studiate per medio de un precise technica a cancellation de patronos specular.

Inter quatro e sex cancellationes esseva determinate pro cata subjecto. Iste datos esseva comparate geometricamente con le datos obtenite ab un modello tridimensional del torso human. In cata subjecto le equivalente location de dipolo cardiac esseva determinate. Il esseva trovate que le technica es practic como methodo de recerca e que illo non es excessivemente lente. Le technica es discutite brevemente. Es presentate resultatos que indica que le centro electric del dispolarisation in nostre subjectos se trovava presso al estimate centro anatomic del ventriculos.

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THE RELATIONSHIP BETWEEN THE PRESSURE SUSTAINED BY THE VARIOUS CARDIAC VALVES AND THE RELATIVE FREQUENCY OF THEIR INVOLVEMENT IN RHEUMATIC FEVER

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IT LONG has been recognized that pressure differences in the two sides of the heart might be related to the greater frequency of rheumatic valvular involvement on the left side than on the right. Apparently not recognized in the literature is the very close relationship between the distribution of rheumatic valvular lesions and the pressures sustained by the various valves during the cardiac cycle.

The pressure sustained by the mitral valve is that of the left ventricle, which approximates systolic aortic blood pressure; the pressure sustained by the aortic valve is that of diastolic aortic blood pressure; the pressure on the tricuspid valve approximates systolic pulmonary artery pressure; and the pressure sustained by the pulmonary valves is that of diastolic pulmonary artery pressure.

In Table I is listed the distribution of rheumatic valvular lesions recorded in published reports of four series of necropsies. For ease of comparison, in Table II these numbers have arbitrarily been divided by a number that makes 100 the mitral involvement. This figure approximates the figures 90 to 120 for normal systolic blood pressure; therefore, the numbers for valvular involvement can be compared with the pressures sustained by the respective valves. Because of the deviation of the Moore series from the others, it has been calculated separately, as well as with the other groups.

In each series, the distribution of valvular lesions follows the same order as the pressure sustained by the valves. Furthermore, this distribution is highly correlated with the pressure sustained by the valves, apparently the only exception to this being in the possible slight increase in right-sided involvement, in proportion to the pressure sustained by the corresponding valves. This increase over expected incidence might easily be accounted for by the increased pressure in the pulmonary system, secondary to mitral stenosis in many of these cases.

This close relationship of rheumatic valvular distribution and pressure seems to be one of the best evidences in support of the concept that pressure plays a part in localization of rheumatic valvular lesions. As such, it not only helps considerably in explaining the distribution of these lesions, but it also supports the possible part played by pressure and chronic trauma in the localization of other rheumatic and closely related lesions.

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TABLE I. DISTRIBUTION OF RHEUMATIC VALVULITIS IN FOUR SERIES

VALVE	NUMBER OF INSTANCES IN WHICH VALVE NAMED WAS INVOLVED							
	COOMBS[1]	EDSTRÖM[2]	CLAWSON[3]		MOORE[4]		TOTAL	TOTAL WITHOUT MOORE'S SERIES
			ACUTE	RECURRENT	ACUTE	CHRONIC		
Mitral	97	31	17	17	92	73	327	162
Aortic	57	18	6	14	75	63	233	95
Tricuspid	35	2	3	6	66	10	122	46
Pulmonary	2	1	0	1	33	2	39	4
Number of patients	97	36	18	18	—	—	—	169

TABLE II. COMPARISONS OF RELATIVE INCIDENCE OF VALVULAR INVOLVEMENT* WITH PRESSURES SUSTAINED BY THE VALVES

VALVE	TOTAL	TOTAL WITHOUT MOORE SERIES	MOORE SERIES	NORMAL PRESSURES (BEST AND TAYLOR)[5]
Mitral	100	100	100	90–120 aortic systolic
Aortic	71	59	86	60–80 aortic diastolic
Tricuspid	37	29	48	12–30 pulmonary systolic
Pulmonary	12	2.5	22	10 pulmonary diastolic

*For ease of comparison the numbers and various totals from Table I have been arbitrarily divided by a number which makes the mitral involvement 100; thus, the numbers in the "total column" were divided by 3.3, and those in each of the other two columns were divided by 1.6.

CONCLUSION

Distribution of rheumatic valvular lesions follows the same pattern as, and is approximately proportional to, the particular pressure sustained by each of the valves.

SUMMARIO IN INTERLINGUA

Le distribution de rheumatic lesiones valvular es parallel e plus o minus proportional al pressiones specific que le varie valvulas debe supportar.

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EFFECT OF QUINIDINE ON THE VENTRICULAR COMPLEX OF THE ELECTROCARDIOGRAM WITH SPECIAL REFERENCE TO THE DURATION OF THE Q-T INTERVAL

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PROLONGATION of the Q-T interval has long been accepted as being produced by quinidine administration,[1-15] and the degree of Q-T prolongation has been used as an indicator of the relative quinidine effect upon the heart.[1,2,5,14,15] However, in most of the reports describing a prolonged Q-T duration due to quinidine administration, the U wave was not adequately differentiated from the T wave and the Q-U duration was measured instead of the Q-T duration. The authors found, during their study in the use of quinidine in patients with established atrial fibrillation and atrial flutter,[16] that careful analysis of the electrocardiograms in those patients in whom regular sinus rhythm was restored, showed the Q-T interval to be normal in most of the patients. Furthermore, quinidine produced an increase in amplitude of the U wave, and fusion of the latter with the T wave which became depressed or inverted. It could thus be readily understood that the inclusion of the U wave in the Q-T interval would cause the impression of a prolongation of Q-T. Besides the effects on the T and U waves, quinidine also caused progressive changes of the S-T segments. Therefore, as a result of these changes in the components of the ventricular complexes, a rather characteristic electrocardiographic pattern was observed during quinidine administration.

It is the purpose of this paper to report the changes and measurements of the various components of the ventricular complex of the electrocardiogram observed during quinidine administration to patients with atrial fibrillation and atrial flutter. We have been able to find, in the literature available to us, no reference to such an observation.

MATERIAL AND METHODS

All patients included in this study had either atrial fibrillation or flutter of long duration. Altogether there were 121 patients, most of whom were admitted

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Abridgement of portion of thesis submitted by Dr. Tsung O. Cheng to the Faculty of the Graduate School of Medicine, University of Pennsylvania in partial fulfillment of the requirements for the degree of Master of Science in Medicine.

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in congestive heart failure. Quinidine was administered orally in an attempt to restore the normal sinus rhythm after the cardiac failure had either disappeared or improved. Almost all of the patients received digitalis in the meantime. The dosage schedule of quinidine and its details will be presented in a separate communication.[16] Briefly, 3.2 Gm. of quinidine sulfate was given to the majority of the patients orally per day in four divided doses, the initial 0.8 Gm. dose being again divided into two halves given two hours apart. This dosage was continued every day till either conversion to sinus rhythm or toxic manifestations occurred. Rarely was the daily dosage increased beyond 3.2 Gm. Quinidine was discontinued within forty-eight hours after normal sinus rhythm was restored.

In all the cases studied, venous blood was drawn daily two hours after the morning dose, and plasma quinidine level determined in duplicate by the fluorometric method of Brodie and Udenfriend.[17] Actual procedure followed was based on Linenthal's modification[15] of the Brodie method. The specificity of this method has been investigated by Linenthal and associates.[15] No drug known to be capable of interfering with the method of quinidine level determination was given. In this laboratory the experimental error was calculated on the basis of repeated determinations on identical samples and on the basis of known dilutions, and found to be ± 0.2 mg. per liter. Determinations of blood quinidine level were continued daily until twenty-four hours after a zero level had been reached.

Electrocardiograms were recorded daily on the same day at about the same time the blood was drawn for determination of quinidine level. In most of the patients, all three standard limb leads and three precordial leads, V_1, V_2, and V_4, were taken daily or several times a day, whenever transient changes were anticipated. The electrocardiogram was registered with the Sanborn, Cambridge, and General Electric direct-writing electrocardiographs.

For analysis of the Q-T and Q-U intervals only cases were chosen if they fulfilled all of the following criteria:

1. The sinus rhythm after conversion must be regular and have no appreciable variation in the cycle lengths.

2. Corresponding blood levels of quinidine at the same time as the electrocardiogram was registered must be available.

3. Only those could be used in which the electrocardiographic tracings were technically good, and adequate differentiation between the T and U waves possible.

4. The sinus rhythm once restored must be maintained as long as there is measurable concentration of quinidine in the blood. This last criterion needs particular emphasis. All of our patients, with the possible exception of one who had atrial fibrillation of an undetermined etiology, had some form of heart disease; it is obvious that the Q-T interval might show significant deviation from the normal, even before the administration of quinidine.[11] Therefore, to determine the influence of quinidine upon the Q-T interval, the latter measure-

ment, obtained at the time when there was no measurable concentration of quinidine in the blood, must be available for comparison.*

Altogether fifty-one cases which fulfilled the above criteria were selected from our series for analysis of the Q-T interval; twelve cases received more than one course of quinidine therapy. A total of 70 courses of quinidine therapy were given with successful restoration of normal sinus rhythm. In four cases that were treated during the early period of our study, only Lead II was used (26 one-lead tracings). In forty-seven cases (66 trials) the three standard limb leads and three precordial leads, V_1, V_2, and V_4, were used (343 six-lead tracings).

The Q-T interval was measured from the beginning of the QRS complex to the end of the T wave. The end of the T wave was the point where this wave reached the base line; in cases where T did not return to the base line because of partial fusion with the U wave, the sudden change of slope, a notch, or a kink between the T and U waves was used to determine the approximate end of T.†[18,19] The Q-U interval was measured from the beginning of the QRS complex to the end of the U wave; the latter could be determined more or less accurately only at low heart rates, and with a stable base line. When there was a rapid heart rate (over 100) with superposition of P on U, the measurements became less amenable and unreliable. Then the QaU was measured, from the beginning of the QRS complex to the point on the U wave most distant from the base line or the apex of the U wave. In cases which showed intraventricular block the difference between the actual duration of QRS and the expected upper normal limit of 0.10 second was subtracted from all measurements, which included the Q-T, Q-U, and QaU.

All the measurements, Q-T, Q-U, and QaU, were done in Leads V_2 and V_4, since the QRS complex began earlier, and the distinction between T and U wave was generally clearest in leads taken over the mid-precordium. In the precordial leads situated further to the left, the U wave was usually very small and, even if markedly elevated in comparison with its normal size, might still remain absolutely small and inconspicuous. In the precordial leads situated further to the right, the T wave usually remained positive and in many cases fused with a normal or exaggerated U wave, so that the apex of a combined large T-plus-U wave probably corresponded neither to any part of the T wave nor to the apex of U, but to a point located somewhere between the T and the U wave.

The duration of the Q-T interval was expressed as a percentage of the expected Q-T interval for the heart rate, according to an empirical curve based on averages of 5,000 cases.[9] The duration of the Q-U and QaU interval was likewise expressed as a percentage of the expected value for the heart rate, according to an empirical curve based on averages of 100 persons.[21]

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*In a few cases atrial fibrillation recurred before a zero level of plasma quinidine concentration was reached; here the measurement taken at the lowest plasma quinidine level, while the rhythm was still sinus, was employed as a control. In other cases in which more than one course of quinidine therapy was given, if atrial fibrillation recurred before zero level of plasma quinidine concentration was reached at any one instance, measurements taken at zero plasma quinidine level at other times were employed for comparison.

†Surawicz and Lepeschkin[20] pointed out recently that if the notch or kink between the T and U wave was situated more than 1 mm. from the base line, the accuracy of determination of the end of the T wave was not good.

RESULTS

A total of 121 cases of established atrial fibrillation and flutter was encountered during the period of study. Spontaneous restoration of normal sinus

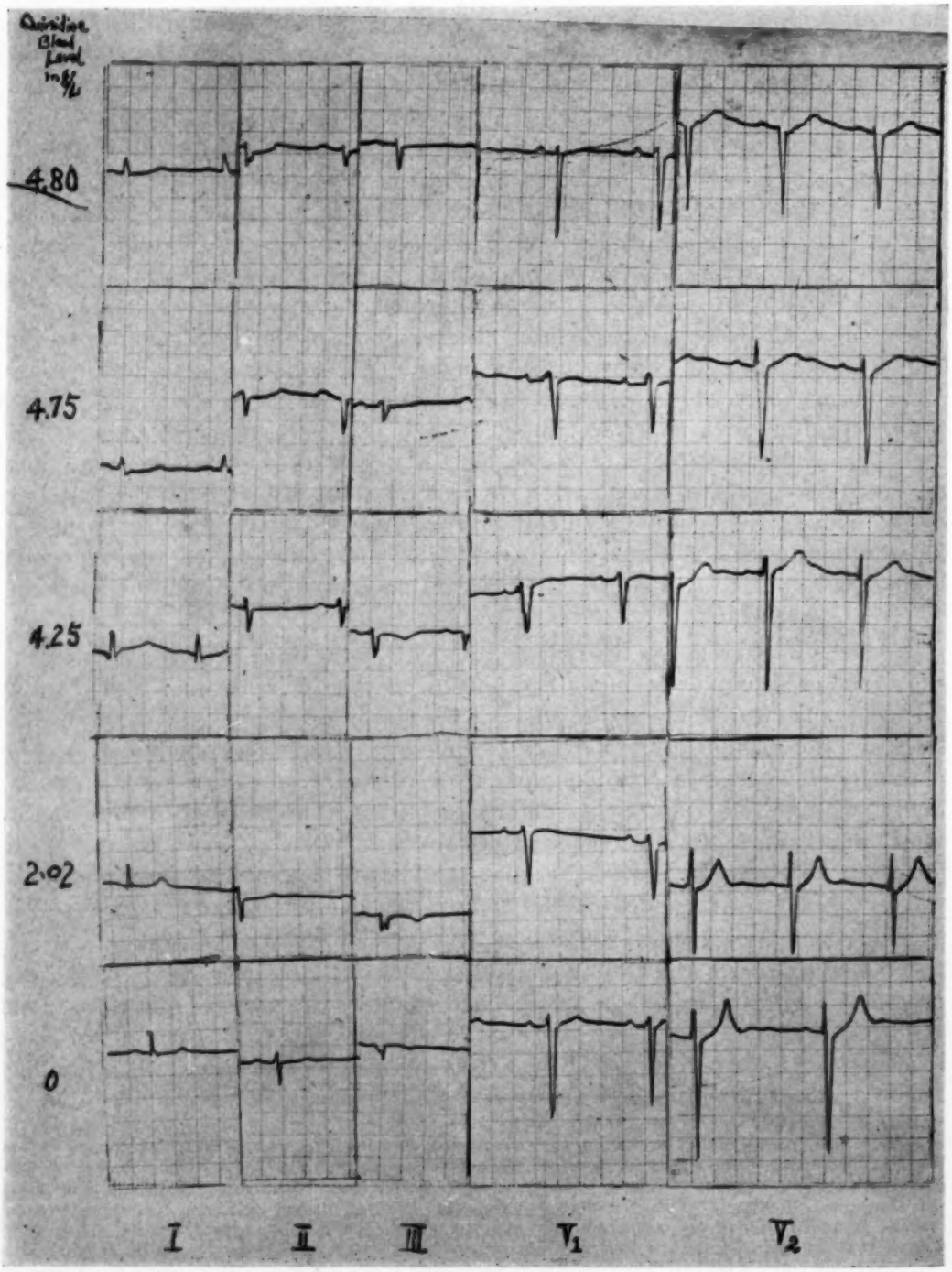

Fig. 1.—Case 48, R.E. Electrocardiograms showing the typical changes in the T and U wave in correlation with the blood levels of quinidine. Note the marked flattening of T with early take-off of the U wave at the peak level of quinidine.

rhythm occurred in ten patients, two of whom had received quinidine at other times without success. Of the 153 courses of quinidine therapy given to the 113 patients, 95 (among seventy-two patients) were successful at restoration of the sinus rhythm. This represents a conversion rate of 62 per cent.

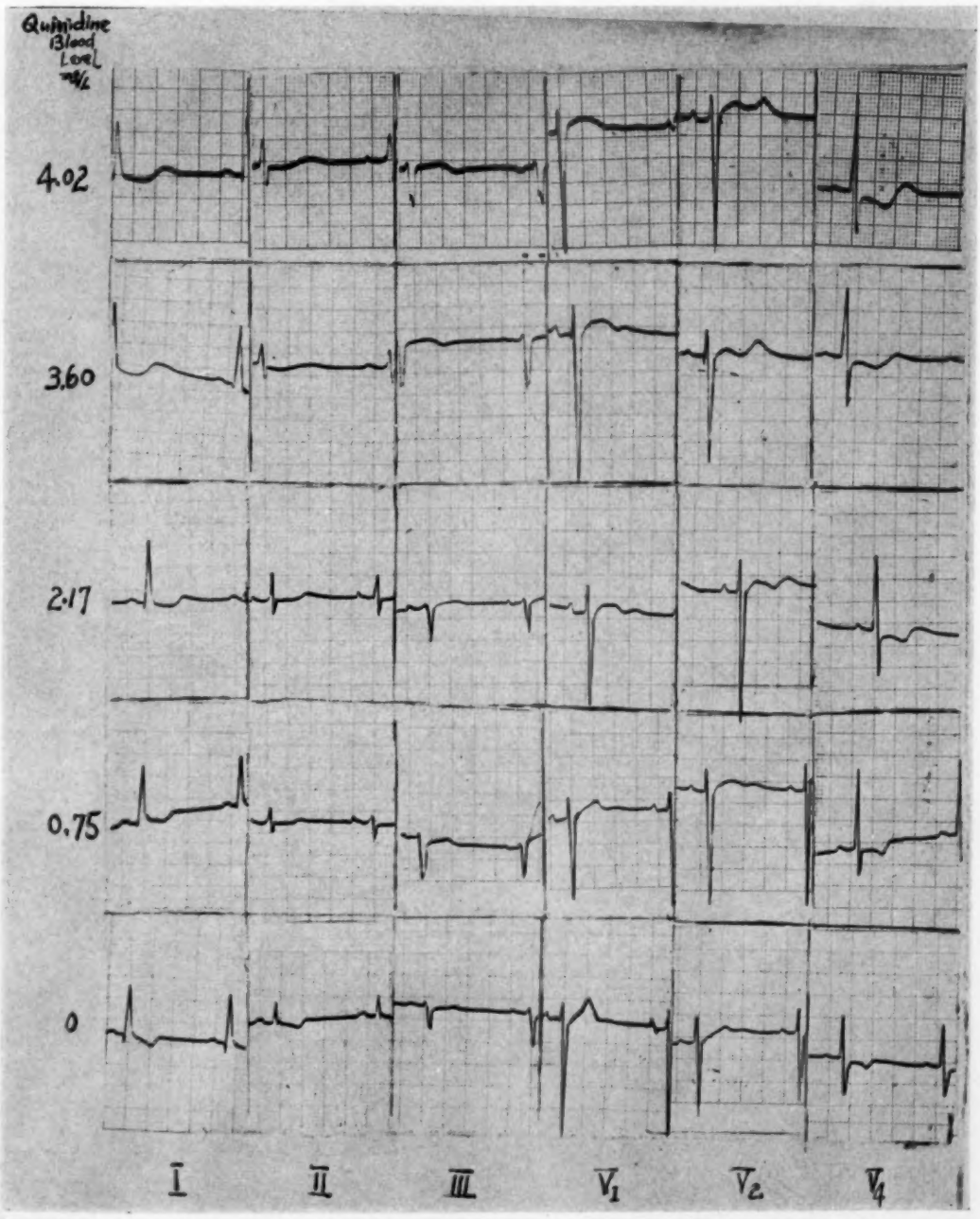

Fig. 2.—Case 54, G.D. Electrocardiograms showing the typical changes in the S-T segment, T and U wave in correlation with the blood levels of quinidine. Note the typical "roller coaster" appearance of the ST-T-U in Lead V_2 of the first and second strips.

QRS Complex.—The QRS complex was prolonged in sixty-nine instances (45 per cent) during quinidine administration; thirty-nine (25 per cent) occurred among cases that were successfully converted and thirty (20 per cent) among cases that failed to be converted. In the converted group the mean prolongation was 40 per cent of the control QRS interval; in the unsuccessfully treated group,

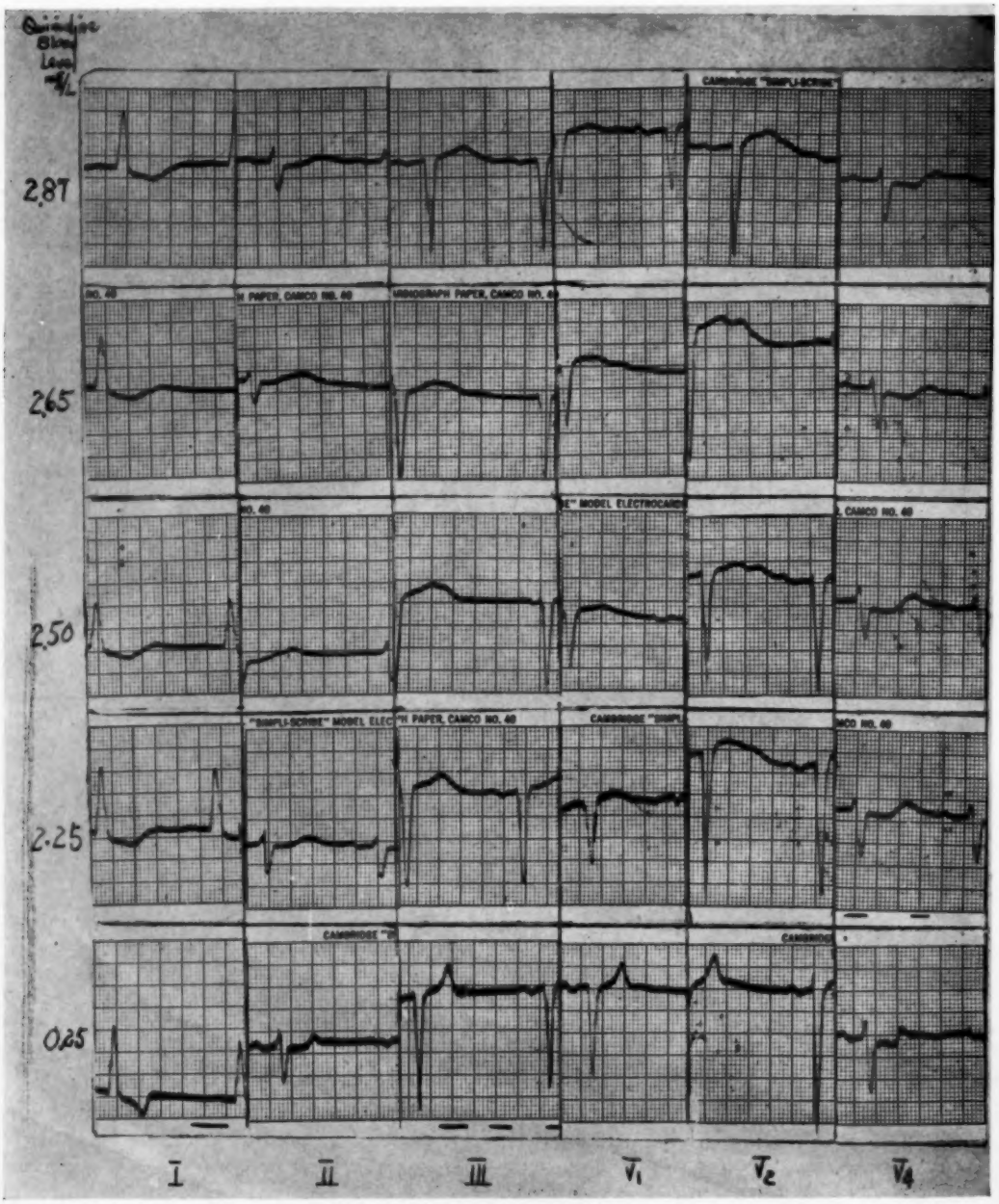

Fig. 3.—Case 61, F.W. Electrocardiograms showing the typical changes in the S-T segment, T and U wave in correlation with the blood levels of quinidine. Note the "double-humped" contour of T-plus-U in V_2 of the second and third strips, and also the U wave "climbing" onto the T wave in V_2 of the top four strips.

50 per cent. The highest degree of prolongation of QRS duration usually occurred in cases with pre-existing bundle branch block, so much so that the pattern simulated that of a ventricular tachycardia. The correlation between the inci-

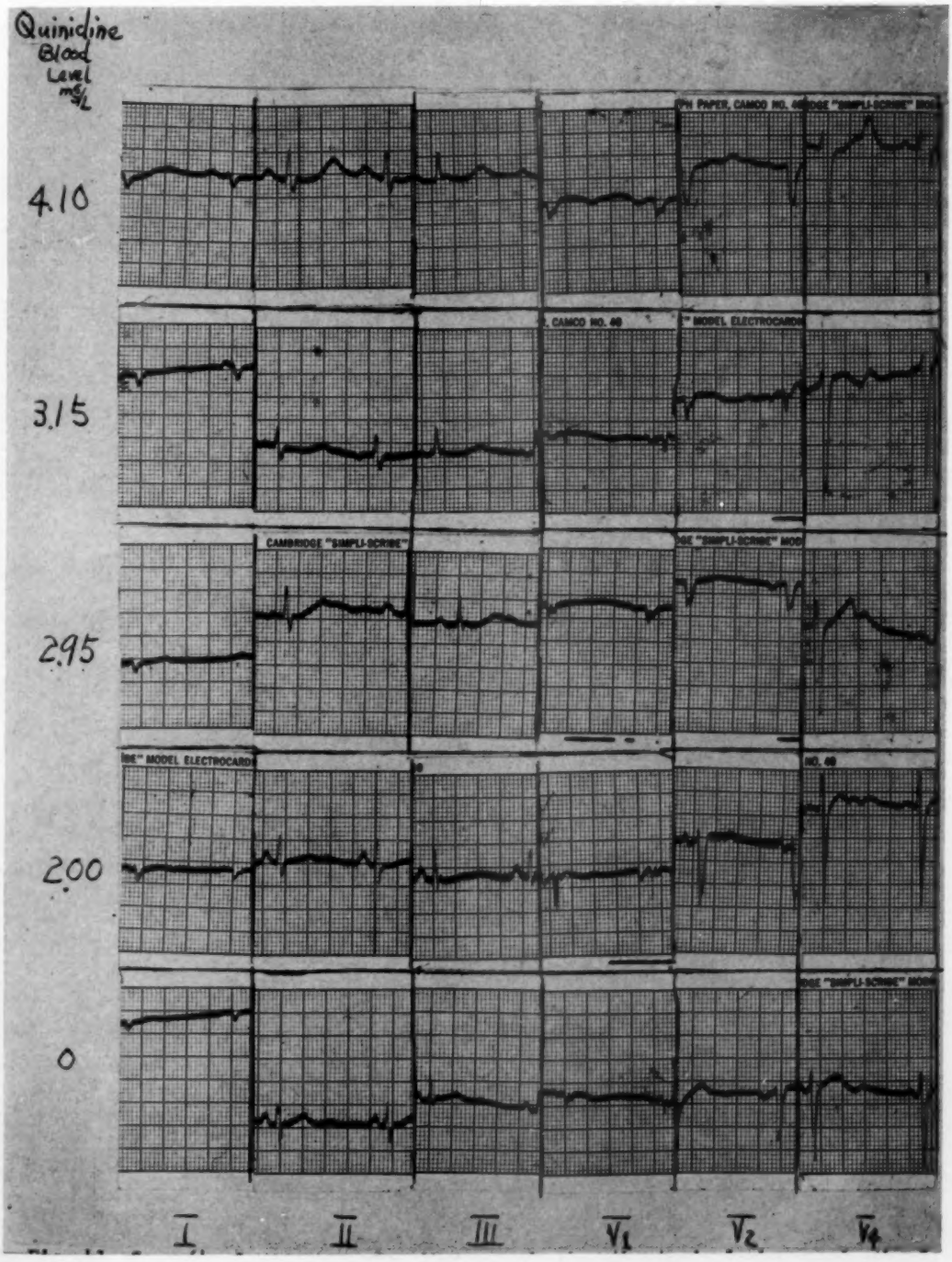

Fig. 4.—Case 41, S.W. Electrocardiograms showing the typical changes in the S-T segment, T and U wave in correlation with the blood levels of quinidine. Note the notched T in addition to a prominent U in V_4 of the fourth strip, and also the "double-humped" contour of the T-U wave in V_4 of the third strip.

dence and degree of QRS prolongation and the blood concentration of quinidine was fairly close, although eighty-four cases—fifty-seven among converted and twenty-seven among failures—showed no change in the QRS duration despite

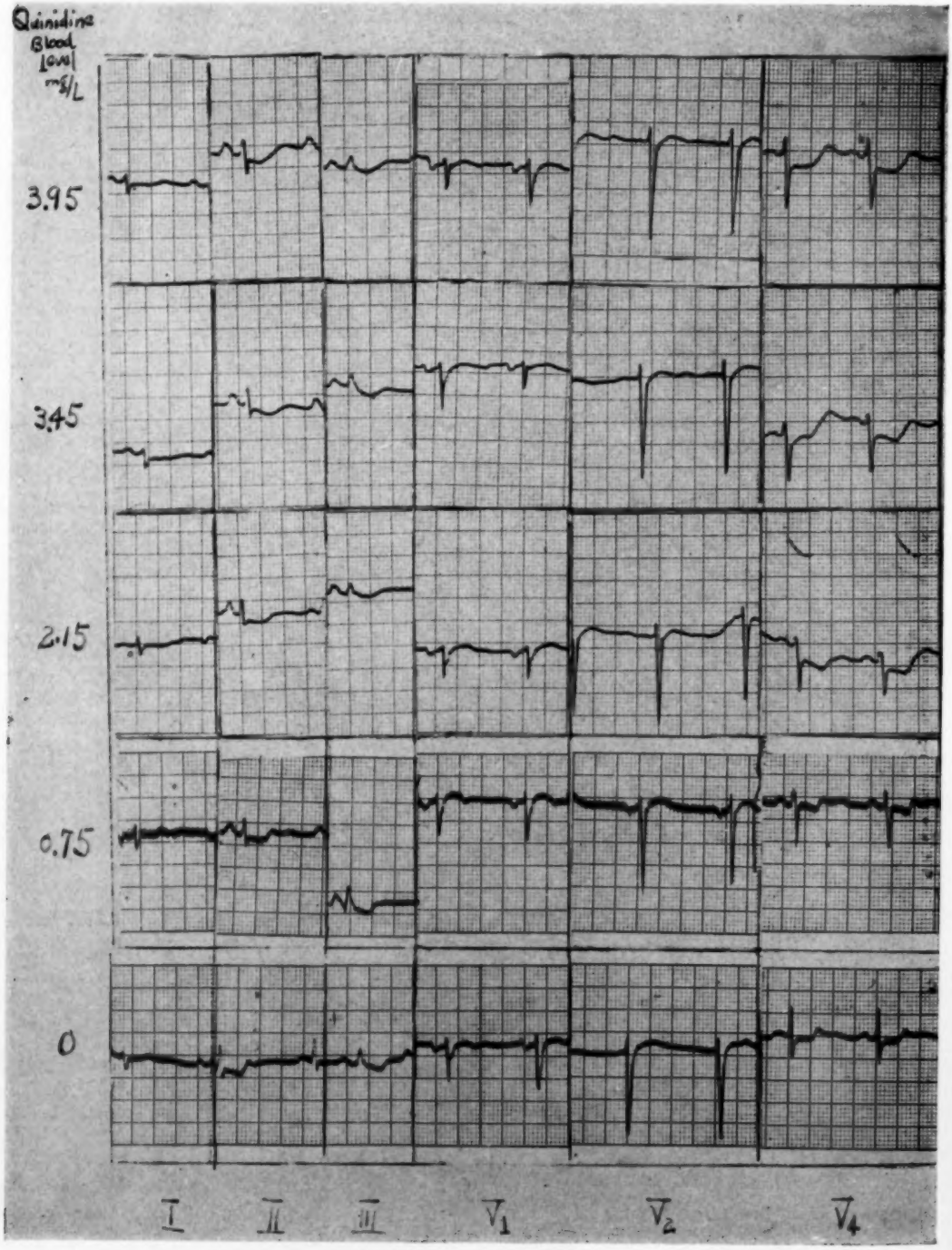

Fig. 5.—Case 90, B.R. Electrocardiograms showing the typical changes in the S-T segment, T and U wave in correlation with the blood levels of quinidine. Note the "double-humped" contour of T-plus-U in V_4 of the fourth strip.

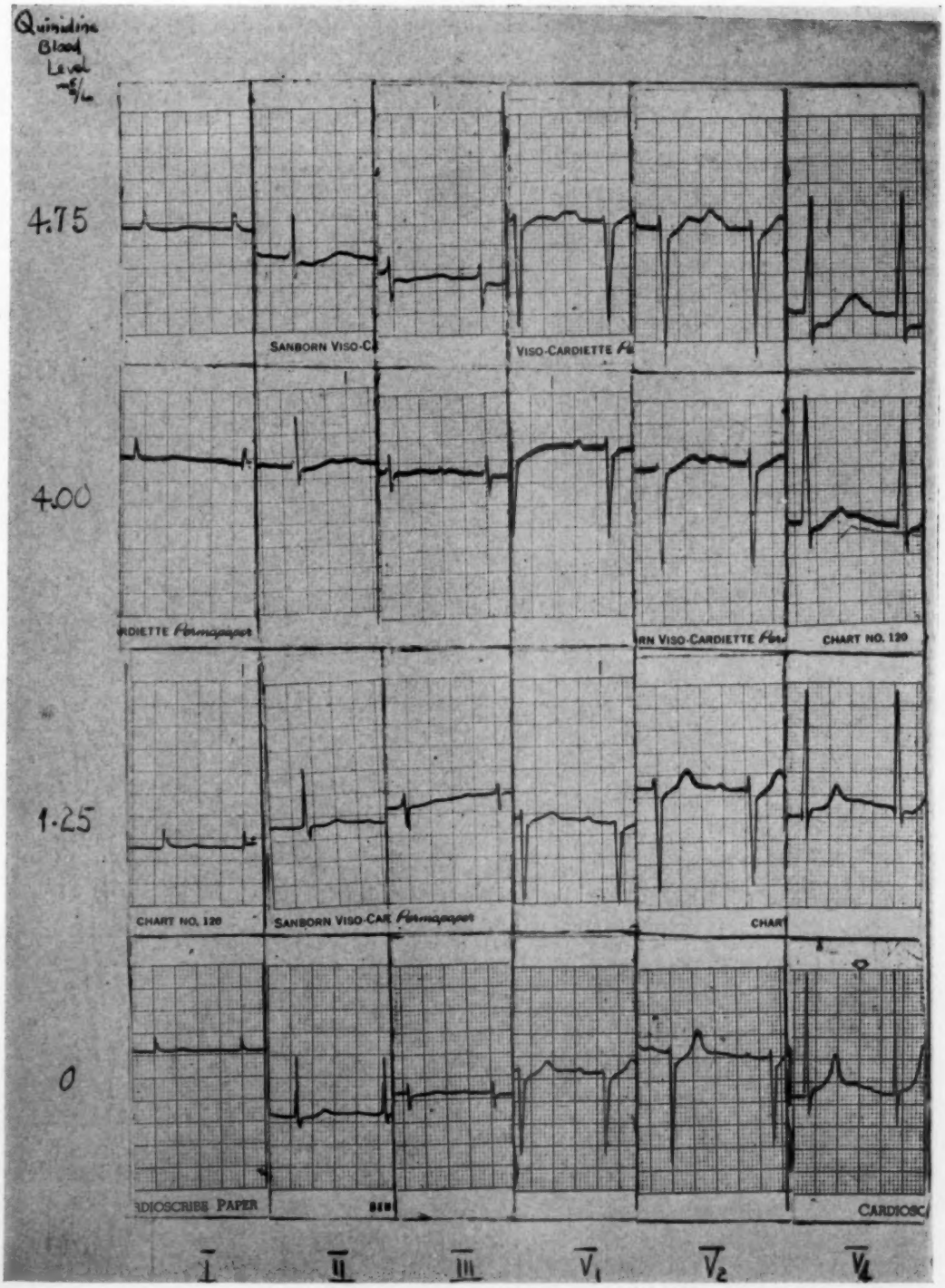

Fig. 6.—Case 92, J.S. Electrocardiograms showing the typical changes in the S-T segment, T and U wave in correlation with the blood levels of quinidine. Note the huge U wave fused with the P wave in V_1, V_2 and V_4 of the first strip; there was also a prolonged P-R interval at the blood quinidine level of 4.75 mg./L.

full therapeutic doses of quinidine and adequate blood levels. In all instances, the widening of the QRS interval decreased within twelve to twenty-four hours after the lowering of the blood level of quinidine.

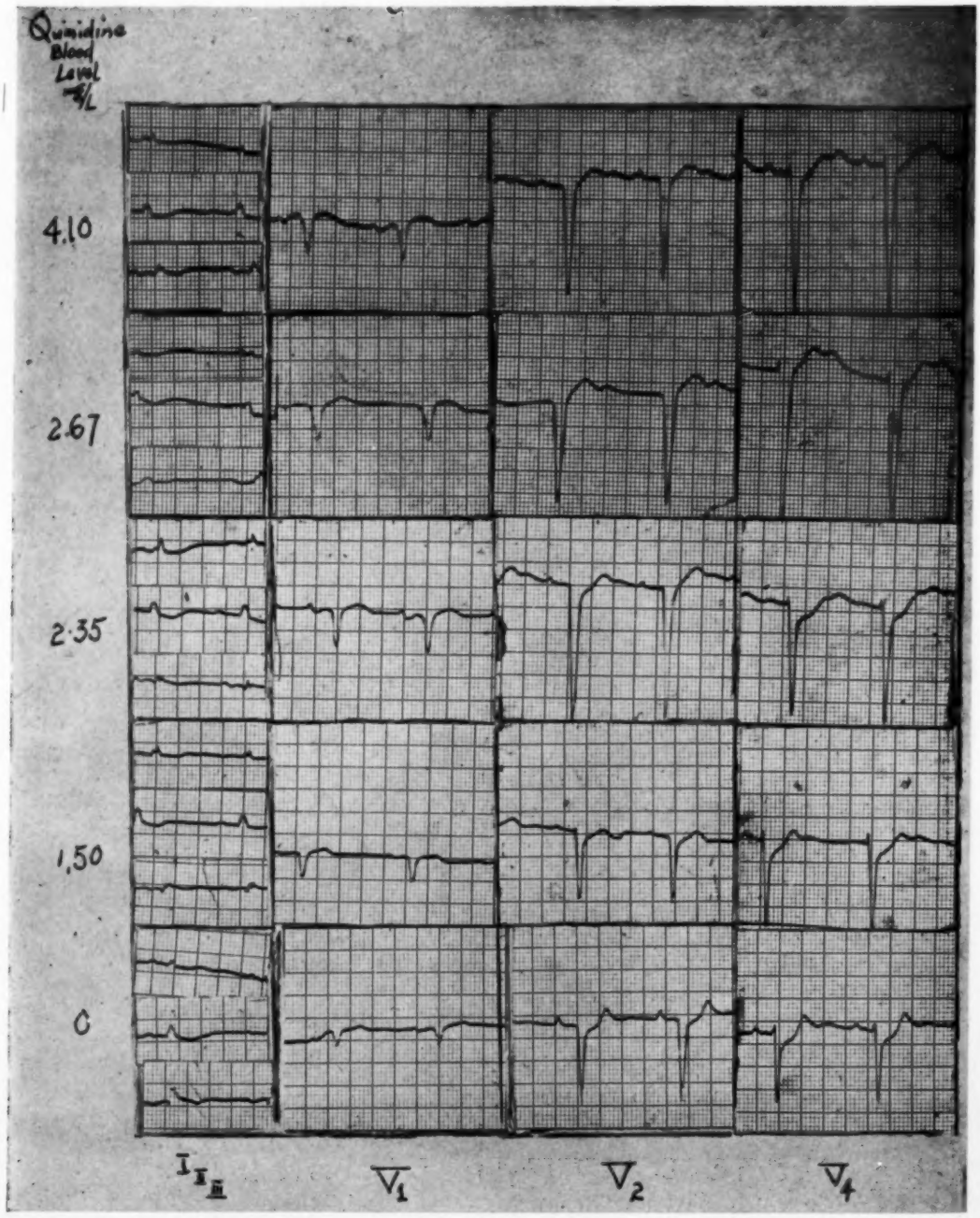

Fig. 7.—Case 96, B.A. Electrocardiograms showing the typical changes in the S-T, T, and U wave in correlation with the blood levels of quinidine. Note the different degrees of T and U fusion in V_4 of the first three strips.

S-T Segment.—The S-T segment usually showed depression in the mid- and left precordial leads, elevation in the right precordial leads, and depression in the standard limb leads. The maximal degree of change corresponded closely with

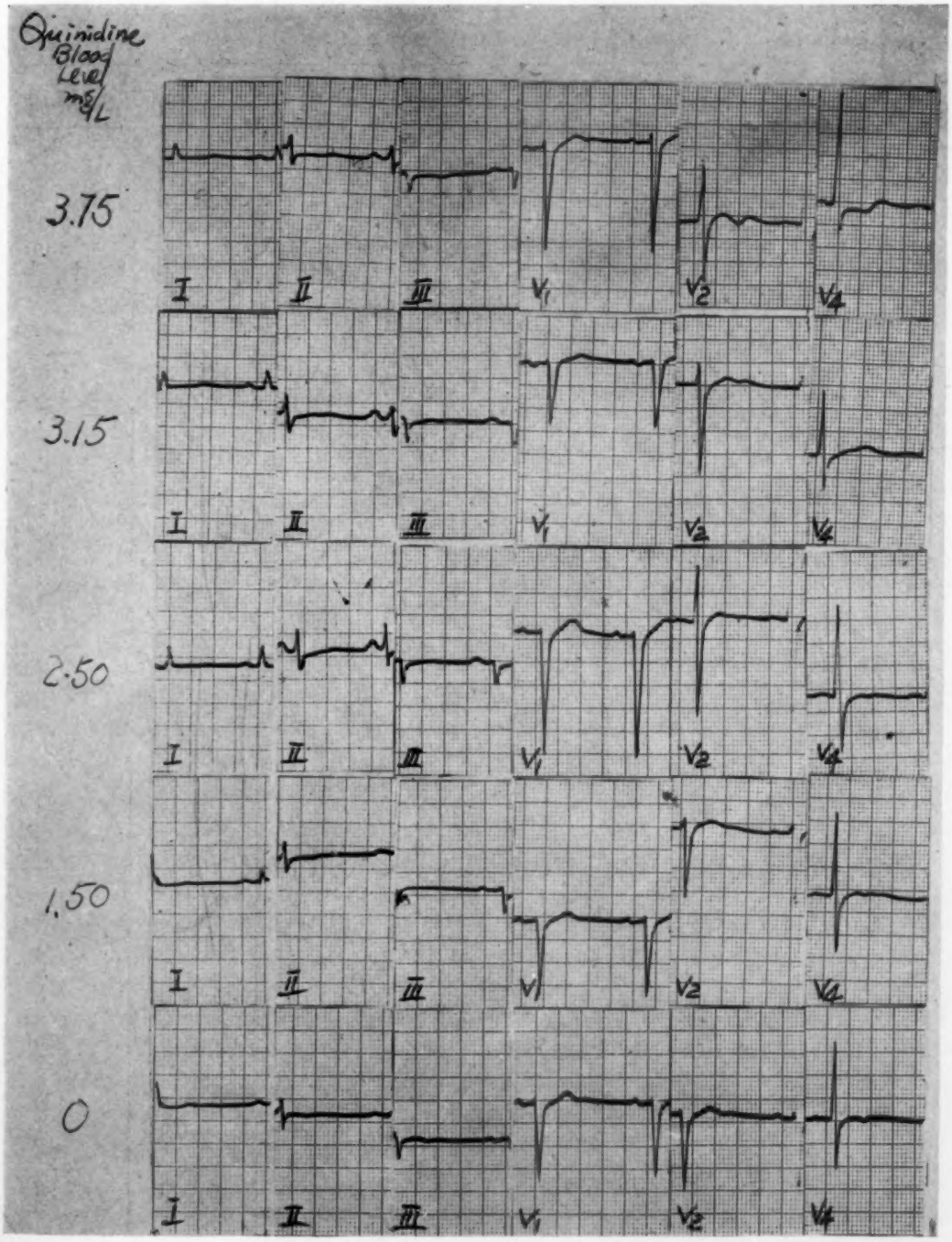

Fig. 8.—Case 102, T.B. Electrocardiograms showing the typical changes in the S-T segment, T and U wave in correlation with the blood levels of quinidine. Note the notched T in addition to the U wave in V_2 and V_4 of the third strip.

TABLE I. SUMMARY OF THE DURATIONS OF Q-T, QaU, AND Q-U IN RELATION TO THE BLOOD QUINIDINE LEVELS

CASE	PATIENT	DEVIATION FROM MEASUREMENTS AT OR NEAR ZERO LEVEL* IN %					
		Q-T		QaU		Q-U	
		MAXIMUM	MINIMUM	MAXIMUM	MINIMUM	MAXIMUM	MINIMUM
11	R.R.	+ 0.9	− 0.8	−12.6	− 2.9	—	—
18	M.K.	−10.0	− 3.6	+ 1.0	− 6.8	—	—
20	H.N.	+ 6.8	− 6.8	—	—	—	—
21	H.G.	+ 5.0	0	+13.7	+ 3.1	+ 4.1	+ 1.0
29	J.S.	+ 2.0	0	+14.7	+ 1.0	0	− 2.0
30	T.J.	+22.7	+12.8	—	—	—	—
32	C.J.	+20.0	+16.0	+ 3.0	0	—	—
33	J.G.	−10.0	− 4.5	—	—	—	—
36	P.V.	+ 1.0	− 1.0	0	− 4.5	—	—
37	A.C.	+ 4.8	—	—	—	—	—
38a	B.R.	+ 4.6	− 4.6	—	—	−18.2	− 1.8
38b	B.R.	+ 3.6	+ 3.6	+ 4.9	+ 4.9	+ 2.8	+ 2.8
38c	B.R.	0	− 4.6	− 8.9	− 4.6	− 7.5	− 5.7
38d	B.R.	+ 4.6	− 8.9	+ 4.9	− 8.9	+ 1.9	− 8.5
39	F.S.	+ 8.9	+ 3.9	+ 3.9	+ 2.8	+ 3.0	+ 3.0
40	F.E.	+ 6.8	+ 1.9	—	—	—	—
41a	J.R.	+ 8.0	+ 2.0	+ 6.1	+ 3.1	0	− 4.0
41b	J.R.	+ 8.0	0	—	—	+ 4.0	+ 4.0
42a	G.T.	+ 4.8	− 2.9	0	− 1.9	+ 4.0	− 1.0
42b	G.T.	+11.6	+ 4.8	−10.0	− 4.6	+ 4.0	+ 1.0
42c	G.T.	+ 6.8	+ 6.8	− 8.2	− 3.7	+ 4.0	− 6.0
43	J.S.	+ 1.9	− 2.9	+10.0	+ 1.0	+ 7.0	− 5.0
46	J.H.	+ 6.0	+ 2.0	− 9.4	− 1.9	− 1.9	− 1.0
48	R.E.	0	− 4.4	+ 7.4	− 3.7	—	—
49	E.Y.	+ 9.0	+ 3.9	−10.0	−10.0	+ 2.0	0
53	L.D.	+ 9.0	+ 5.0	—	—	+ 1.0	− 1.0
54a	G.D.	− 3.9	− 2.9	− 2.9	− 1.0	− 5.0	− 1.0
54b	G.D.	+ 3.8	− 1.0	+ 2.0	0	+ 5.3	− 1.0
56	R.R.	+ 9.0	+ 4.0	+ 1.0	− 4.0	+ 1.0	− 3.0
57	W.G.	+ 9.0	+ 4.0	—	—	+ 4.1	0
58	E.E.	− 8.0	− 2.4	+ 2.0	0	0	0
61	F.W.	−10.0	0	+10.0	− 2.0	0	0
63	A.S.	+ 7.7	+ 5.8	—	—	—	—
64a	S.W.	+ 7.8	− 2.0	− 3.0	− 2.0	− 3.0	− 2.0
64b	S.W.	+ 4.8	0	+ 8.5	+ 2.1	0	0
65	W.C.	+ 4.8	− 2.0	+ 1.0	−12.6	+ 4.0	+ 2.0
67	K.B.	+22.0	+10.0	—	—	+ 7.0	+ 1.0
70a	J.M.	+ 7.8	+ 7.8	—	—	—	—
70b	J.M.	+ 4.9	+ 2.9	—	—	—	—
70c	J.M.	+ 2.9	+ 1.9	—	—	—	—
71	O.L.	+ 4.8	0	+ 2.9	+ 2.9	+ 5.0	0
72a	J.Y.	+ 4.5	0	− 5.0	− 1.0	+ 3.0	0
72b	J.Y.	+ 9.0	+ 7.3	− 1.0	0	− 1.0	− 1.0
78	R.M.	+ 7.8	+ 7.8	− 5.7	− 1.0	− 9.0	− 3.7
80	W.T.	+ 9.0	− 5.0	—	—	+ 3.0	− 3.0
81	A.W.	0	0	0	0	− 2.0	− 1.0
82	M.W.	0	0	+ 8.3	0	+ 3.0	− 8.7
84	W.J.	+ 1.0	− 1.0	—	—	—	—
86	H.L.	+ 2.0	0	+ 2.0	0	—	—
90a	B.R.	+ 2.0	− 3.0	+ 4.0	+ 4.0	0	0
90b	B.R.	− 7.4	− 3.0	+ 6.0	− 6.0	+ 6.0	0
92a	J.S.	− 8.0	− 5.0	− 2.0	− 2.0	+ 1.0	−11.7
92b	J.S.	+ 7.2	0	− 2.0	− 2.0	+ 4.0	− 2.0
92c	J.S.	0	− 4.5	+ 6.0	− 2.0	− 9.0	− 2.0

TABLE I—CONT'D

CASE	PATIENT	DEVIATION FROM MEASUREMENTS AT OR NEAR ZERO LEVEL* IN %					
		Q-T		QaU		Q-U	
		MAXIMUM	MINIMUM	MAXIMUM	MINIMUM	MAXIMUM	MINIMUM
94a	A.A.	+ 4.8	+ 4.8	+ 1.0	0	+ 4.0	− 2.0
94b	A.A.	+14.3	− 6.7	+ 2.0	0	+ 2.0	−10.0
95	H.E.	0	− 4.5	+ 7.4	0	—	—
96	B.A.	+ 4.5	− 4.5	+ 1.0	0	+ 3.8	− 2.8
97	J.C.	+ 9.5	− 4.8	0	− 5.0	+ 2.0	− 4.0
98a	P.F.	+ 4.0	+ 1.0	+ 1.0	− 1.0	—	—
98b	P.F.	+ 4.0	0	—	—	—	—
98c	P.F.	+ 6.5	− 4.0	+ 1.0	− 3.0	—	—
102a	T.B.	+ 7.8	+ 3.0	+ 5.0	− 4.0	—	—
102b	T.B.	+ 7.8	+ 1.0	+ 4.0	− 2.0	—	—
106	C.Mc.	+13.0	+ 9.0	+ 4.0	+ 2.0	—	—
110	M.E.	+26.0	+16.0	− 7.0	− 4.0	—	—
111	W.G.	+11.0	− 1.0	+ 4.0	− 4.0	—	—
112	E.W.	− 4.5	− 2.0	− 6.0	− 4.0	—	—
114	O.K.	+20.0	+ 7.0	+ 4.0	+ 1.0	—	—
121	M.D.	+15.0	+ 5.5	+ 3.0	+ 2.0	—	—

*In some cases atrial fibrillation, or flutter, reeurred before the blood level of quinidine declined to zero; measurements taken at the lowest blood quinidine level during the period of regular sinus rhythm was employed as a control. This arbitrary rule also applied to patients who received more than one course of quinidine therapy, and who did not each time maintain the regular sinus rhythm till the blood level of quinidine became zero, or almost zero.

the peak level of quinidine in the blood. As the blood level declined, the S-T segment in the mid-precordial leads gradually changed from a descending, "sagging" course to a horizontal, and finally to a normally ascending course. In the right precordial leads the reverse took place.

T and U Wave.—The T wave generally became depressed, flattened, diphasic, or inverted. At times the T wave might be notched. A U wave appeared if not previously present; the U wave usually became taller if already present and tended to "climb" onto the descending limb of the T wave. At the peak blood level of quinidine the T wave usually became totally negative and the ventricular complex seemed to consist entirely of a depressed S-T segment continuous with a tall U wave. As the level of quinidine in the blood began to decline, the depressed S-T segment began to return to the base line and the T wave began to emerge. In the meantime the U wave began to recede as the T wave began to grow taller and taller, until finally the T wave assumed its normal upright contour with its apex higher than that of the U wave.

Examples of some of the changes which occurred are illustrated in Figs. 1-8.

Q-T, Q-U, and QaU Intervals.—The Q-T, Q-U, and QaU intervals are measured in all cases and the results summarized in Table I. As can be seen in Table I, in sixty (85 per cent) of the seventy patients given quinidine for conversion of atrial fibrillation and flutter to a regular sinus rhythm, the Q-T duration

showed an average increase of 3.3 per cent, the changes ranging from a maximal increase of 9 per cent to a maximal decrease of 10 per cent. They are insignificant changes. In only ten patients (15 per cent) who received quinidine, the Q-T duration showed a maximal increase from 11 to 26 per cent, the average being 17.6 per cent.

In the cases in which the U wave and the apex of the U (aU) could be identified and measured accurately, the Q-U and the QaU duration showed an average deviation of 0.5 and 0.9 per cent from normal, respectively. This indicates that not only the end but also the apex of the U wave appeared at the expected normal time under the influence of quinidine.

DISCUSSION

That quinidine slows conduction in the heart muscle has long been known. This action of quinidine is shown electrocardiographically by the slowing of the atrial movement in atrial fibrillation and flutter, prolongation of intraventricular conduction (prolonged QRS time) and prolongation of atrioventricular conduction (prolonged P-R interval).[6] The effect of the prolongation of the QRS time is of practical importance. About half of our cases showed a prolongation of the QRS interval; the mean prolongation was 40 per cent and 50 per cent of the control values in the converted and unsuccessfully treated groups, respectively. Many patients, however, showed no change in the QRS duration, despite full therapeutic doses of quinidine. The highest degree of prolongation of QRS duration usually occurred in cases with pre-existing bundle branch block, so much so that the QRS complex lost the contour of a normal ventricular group, and the picture resembled that of a ventricular tachycardia. This is often a precursor of ventricular fibrillation.[6] Marked prolongation of the QRS interval, varying from 33 to 100 per cent, occurred in four of the eight deaths that occurred during, or following, quinidine therapy in our study.[16] We felt that quinidine should be discontinued if the increase in the QRS time exceeded 50 per cent of the control value but should be used with great caution when the increase in QRS duration exceeded 25 per cent. This coincides with the experiences of Gold[6] and of Sokolow.[22]

The effect of quinidine on the electrical systole of the heart (Q-T interval) has long been thought to be a prolongation.[1-15] From our study, however, it is shown that in the majority of the cases (85 per cent) given quinidine the duration of the Q-T interval, corrected for the heart rate, is not prolonged. In most of the reports describing a prolongation of the Q-T interval due to quinidine administration the U wave was not adequately separated from the T wave and the Q-U duration was measured instead of the Q-T duration. Bellet and his associates[11,23] made no distinction between the Q-T and Q-U segment, and considered the U wave a part of the Q-T segment (electrical systole). Since the Q-U duration is usually 40 to 70 per cent greater than the Q-T duration,[20] it would be expected that measurement of the Q-U instead of Q-T naturally gave only very high value for the Q-T duration (a "pseudo-prolongation" of the Q-T[24]).

The greatest difficulty in the determination of the Q-T interval is encountered when the U wave begins earlier than the end of the T wave and the two deflections

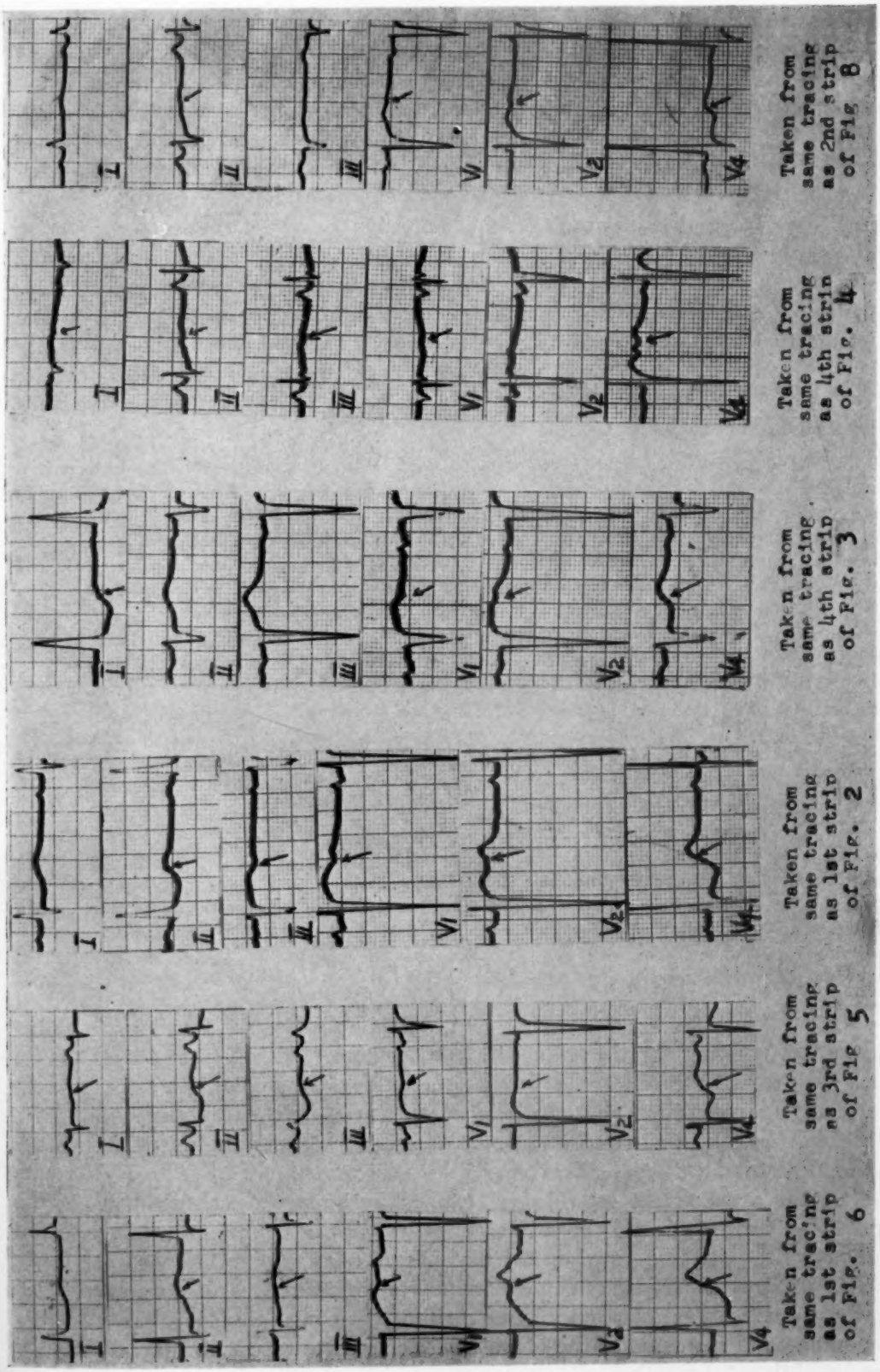

Fig. 9.—Illustrating the synchronization method of identifying the junction between T and U wave as indicated by the arrows.

are superposed upon each other. Such a fusion of the T and U wave may be confused with a notched T wave with or without a prolongation of the Q-T interval. In the majority of the cases in which a sufficient number of unipolar precordial leads has been registered, an adequate notch or kink between the descending or ascending limb of T and the ascending limb of U is present at least in some of the leads.[19] The best leads for the detection of this kink or notch are the midprecordial leads, V_2 and V_4. However, in some cases the merging of T and U may be complete and no notch or kink is visible in any of the leads registered. It may then be difficult to determine whether the pattern which thus results represents a Q-T interval of normal duration accompanied by merging or fusion of the T and U, or whether the pattern is produced by a true prolongation of the Q-T interval, with or without notching of the T wave, and with an inconspicuous U wave. When there is doubt as to whether a suspicious undulation with or without notching represents a T or a U wave, the following means have been recommended for differentiation:

1. As many leads, especially the precordial leads V_2 and V_4, as possible should be taken, since one of these leads usually reveals a clear-cut boundary (a notch, a kink, or a change of slope) between the true T wave and the U wave. All the other leads could then be synchronized with that particular lead, provided cycle lengths were identical (Fig. 9). Then, the repetition of electrocardiographic tracings at frequent, short intervals (sometimes as often as every few hours) usually reveals a stage where a precise separation of the T and U wave can be made.
2. The duration of the questionable wave after correction for the heart rate and sex can be compared with the same values in normal persons.[21] Such a comparison will show whether these intervals approach most closely the normal values for the T, or those for the U wave.[20]
3. If the electrocardiograms are recorded simultaneously with a phonocardiogram, a summit preceding the second sound is a T wave, and one following the second sound a U wave[19,25] (Fig. 10).
4. The terminal portion of T, following a notch, is usually of short duration (less than 0.15 second), while a U wave is longer; the slope of the T wave exceeds one microvolt per millisecond, while that of the U wave usually does not.[19]
5. The distance between the summits of a notched or a diphasic T wave almost never exceeds 35 to 40 per cent of the distance between the beginning of QRS and the second summit, while the distance between the summits of T and U exceeds this percentage of the distance between QRS and the summit of U.[19] This rule, however, is not infallible, because the U wave may often show an early beginning, "climbing" onto the descending limb of the T wave, thus abbreviating the distance between the summits of T and U. This phenomenon has been seen frequently in our group of patients treated with quinidine.

Since the cardiac rhythm in our group of patients undergoing quinidine therapy was either atrial fibrillation or atrial flutter, all degrees of the S-T, T, and U changes on the electrocardiograms could be evaluated only after the restoration of a regular sinus rhythm. The latter was usually accomplished at or near the peak level of quinidine in blood. As there was no way of depicting the configuration of the ventricular complex with the measurements of its components before the onset of the established atrial arrhythmia, the configuration of the ventricular complex, and the durations of its various components taken within zero to forty-eight hours after the blood level of quinidine became zero, were taken as a control for that particular individual. Changes that were observed after the restoration of normal sinus rhythm at or near the peak blood level of quinidine and regressed as the blood level declined toward zero, were attributed to quinidine.

The S-T segment usually showed at the peak blood quinidine level a maximal depression in the mid-precordial leads, elevation in the right precordial leads, and depression in the standard limb leads. As the blood level declined

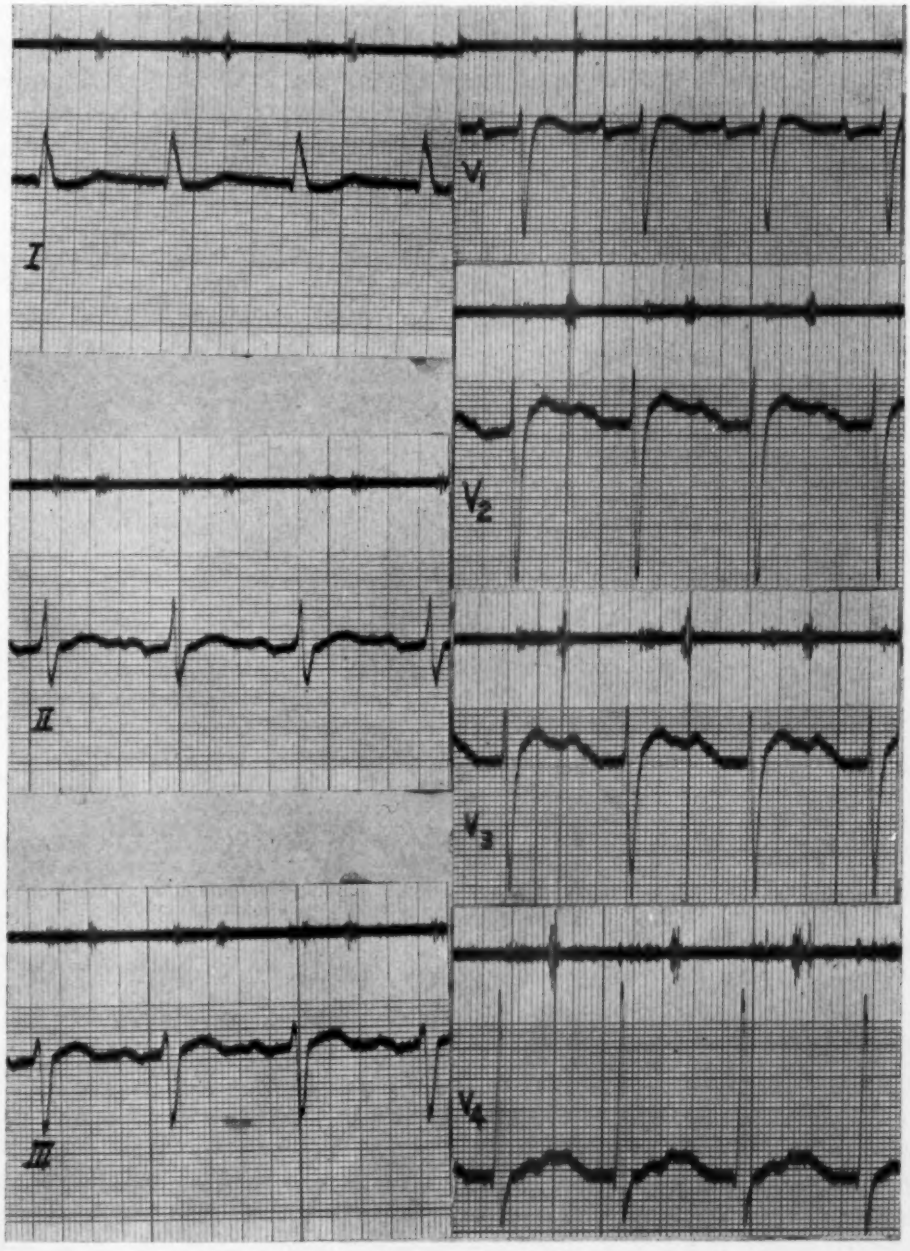

Fig. 10.—Leads I, II, III, V_1, V_2, V_3, and V_4 with synchronous phonocardiograms registered in a patient in whom sinus rhythm was successfully restored with quinidine therapy. The blood quinidine level at this time = 4.10 mg. per liter. A notch synchronous with the second heart sound is clearly seen separating the notched T wave and the prominent U wave in Leads V_2 and V_3. In Lead V_4 the large, broad positive repolarization wave with a notch on its summit could be either a notched T or a T-plus-U wave; the appearance of the second heart sound synchronous with the notch makes it certain that the second summit is a U wave partly fused with the P wave.

the S-T segment in the mid-precordial leads gradually changed from a descending "sagging" contour to a horizontal and, finally, to an ascending course. In the right precordial leads the reverse took place.

The T wave generally became inverted, diphasic, or merely decreased in height at the peak blood quinidine level. A U wave usually appeared and often was exaggerated in amplitude. The U wave tended to climb onto the descending limb of the T wave. At some time the voltage of the U wave might be so large and that of the T wave so small that the ventricular complex seemed to consist entirely of a depressed S-T segment, continuous with a tall U wave. The latter

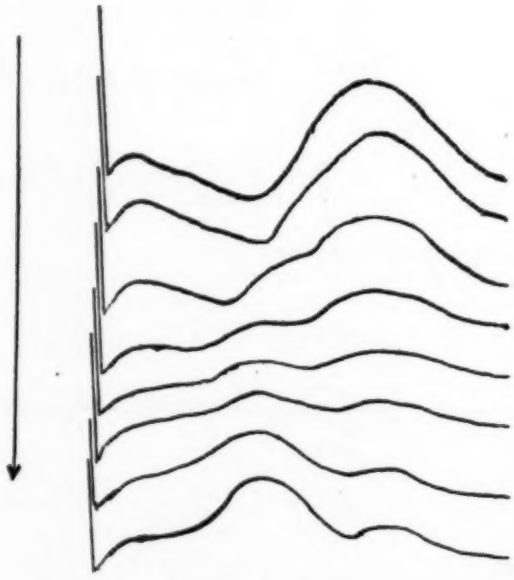

Fig. 11.—Schematic diagram showing the changes in S-T, T, and U in the mid-precordial lead, V_4, as the blood level of quinidine continued declining in the direction of the arrow. The topmost curve thus corresponded to the peak level, and the lowest to the zero level of quinidine in blood. Also see text.

taken alone could not be differentiated from an unusually long and large T wave, and the Q-U duration would thus be mistaken for a greatly prolonged Q-T interval. As the blood level of quinidine began to decline, the T wave started to emerge, first as a notch in the ascending limb of the U wave which began to decrease in height and later as a diphasic wave definitely separated from the U wave by a notch, or kink (Fig. 11). A triple contour resembling a rolling countryside might occur as a result of combination of a depressed S-T segment, a decreased T wave, and a relatively prominent U wave. The U wave showed progressive diminution of magnitude, as the T wave began to become more and more positive. Because of the simultaneous operation of these two changes, at one stage the T and U were about equal in amplitude, imparting to the T-U segment the "double-humped" contour of a Bactrian camel (Figs. 3-8). The T wave continued to grow taller and the U wave to recede as the blood level of

quinidine continued to decline, until finally the T wave assumed its normal upright contour, with its summit higher than, and well apart from, that of the U wave.

The T wave itself might be notched with or without an actual prolongation of the Q-T interval. In this case the notch could be mistaken for the end of the T wave, while the section of T beyond the notch might be considered as a U wave. This error would particularly be prone to occur if the notch approached, or reached, the base line, and if a distinct U wave was not present at the same time. However, other leads taken simultaneously, or subsequently synchronized, with the doubtful lead, usually showed T waves of the typical form, the summits

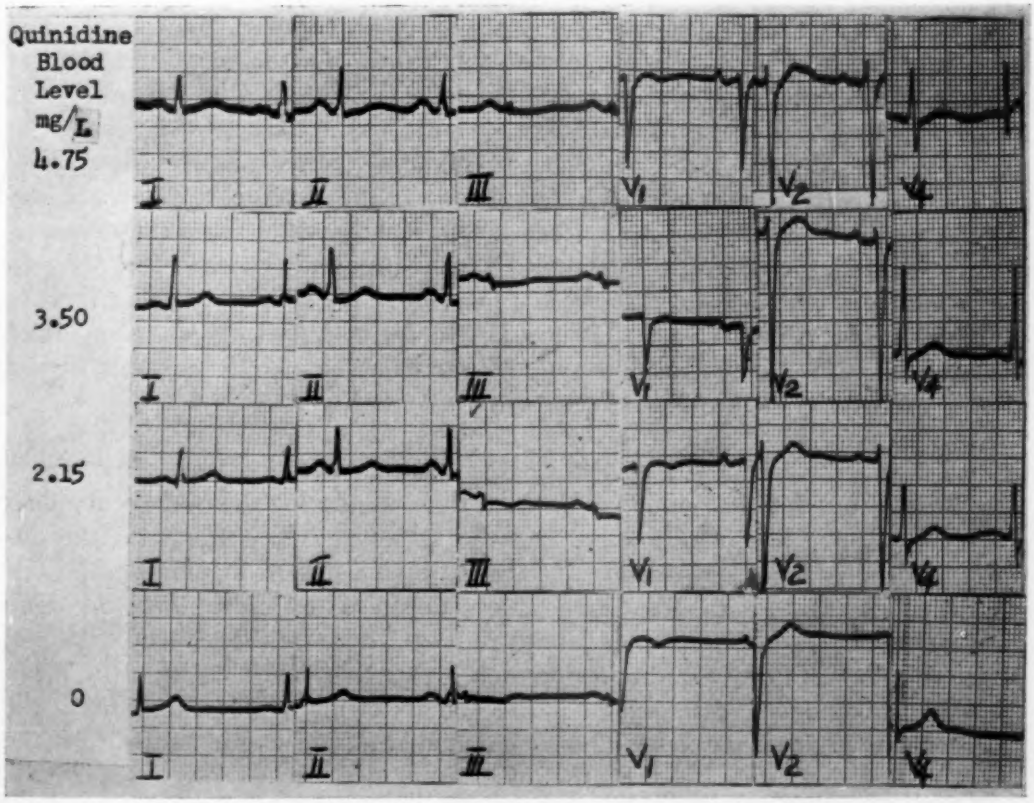

Fig. 12.—Case 32, C.J. Electrocardiograms showing actual prolongation of the Q-T interval with notching of the T wave (V_2 and V_4 of the first strip) observed during quinidine therapy. The Q-T duration decreased as the blood level of quinidine declined.

of which coincided with the notch. As an example, the notched T wave in Leads V_2 and V_4, taken at the peak blood level of quinidine of 4.75 mg. per liter in Fig. 12, could be synchronized with a smooth T wave in Leads I and II of the same tracing; besides, a distinct U wave was present in addition to the notched T wave in Leads V_2 and V_4. On the other hand, in Fig. 8, the notch on the summit of the T-U segment in Leads II and V_2, corresponding to the blood level of quinidine of 3.15 mg. per liter, was actually the notch between T and U fused together, readily identifiable by synchronization with Leads I, III, and V_4 of the same electrocardiogram.

To recapitulate, the most typical electrocardiographic pattern in patients receiving quinidine is characterized by an S-T segment, and T wave of opposite polarity to a U wave of increased amplitude, while the Q-T interval itself, corrected according to the heart rate, is in most cases normal in duration. The total appearance can be compared with a roller coaster. This electrocardiographic pattern is uniquely characteristic. However, a pattern bearing close resemblance to the pattern produced by quinidine may appear in hypopotassemia, and the similarity may become so great that the two patterns may become practically indistinguishable.[20]

The maximal changes of each of the three components of the ventricular complex (S-T segment, T and U wave) influenced by quinidine appear in different leads in different degrees. They are most pronounced in Leads V_2 and V_4, but are usually not so obvious in the limb leads. The degree of the changes of each of the three components may be independent of that of the other two, and may vary not only from patient to patient, but also in the same patient at different times with different blood levels of quinidine. In some cases the changes of the T wave are mainly in the foreground, while the U waves are only slightly increased in voltage (Fig. 1). In other cases the U wave changes predominate, while the changes in the S-T segment and T wave are not so marked (Fig. 7). In still other cases, the S-T changes are the most obvious, while the T and U wave changes are not as prominent. This usually happens in patients who show a low T and U wave and a tendency to only minimal degree of S-T depression when the quinidine level in the blood is zero, or near zero (Fig. 8).

An attempt was made to express the magnitude of quinidine effect on the electrocardiogram by measuring the vertical distance between the apex of the T and the apex of the U from the baseline and then correlating the numerical values with the blood levels of quinidine. In the normal electrocardiogram the difference would be a positive one, because the T wave is always higher in amplitude than the U wave. As the T wave begins to decrease and the U wave begins to increase in height, the difference would diminish and the value would be less positive. As the T wave decreases further, a negative value will result. When the peak blood level of quinidine is reached following quinidine therapy, the polarity is completely reversed and a maximal negative value results. As the blood level of quinidine declines, the difference would be less and less negative, until a positive difference is again reached. The difference becomes more positive as the blood level approaches zero. Table II outlines the correlation in a numerical fashion of the differences between the summits of T and U (the "T-U difference") and the blood levels of quinidine in eight of the patients whose electrocardiographic tracings were illustrated in Figs. 1-8. It can be seen from the table that the difference between the summits of T and U wave bears an inverse relationship with the blood quinidine level. It should, however, be noted that the electrocardiographic changes, as judged by the T-U differences, did not always bear a parallel or a linear relationship with the blood level of quinidine. For example, in Case 96 (Fig. 7), while the T-U difference at a blood level of quinidine of 4.10 mg. per liter was -1, at a blood level of 2.67 mg. per liter it became $+0.5$; however, at a blood level of 2.35 mg. per liter the T-U difference became -1 again.

TABLE II. CORRELATION OF THE DIFFERENCE BETWEEN THE SUMMITS OF T AND U AND THE BLOOD LEVELS OF QUINIDINE IN 8 PATIENTS WHOSE ECG'S WERE PRESENTED (FIGS. 1-8)

Case 48	Blood level (mg./L.)	4.80	4.75	4.25	2.02	0	Fig. 1
R.E.	T-U difference	+1.5	+1.0	+3.0	+6.0	+7.0	
Case 54	Blood level (mg./L.)	4.02	3.60	2.17	0.75	0	Fig. 2
G.D.	T-U difference	−1.0	−2.0	−1.0	+0.8	+1.0	
Case 61	Blood level (mg./L.)	2.87	2.65	2.50	2.25	0	Fig. 3
F.W.	T-U difference	−0.8	+0.6	+0.9	+1.5	+6.0	
Case 64	Blood level (mg./L.)	4.10	3.15	2.95	2.00	0	Fig. 4
S.W.	T-U difference	−5.0	+0.5	+3.0	+0.5	+3.0	
Case 90	Blood level (mg./L.)	3.95	3.45	2.15	0.75	0	Fig. 5
B.R.	T-U difference	−5.0	−5.0	−4.0	0	+1.0	
Case 92	Blood level (mg./L.)	4.75	4.00	1.25	0	–	Fig. 6
J.S.	T-U difference	−2.0	0	+3.5	+5.0	–	
Case 96	Blood level (mg./L.)	4.10	2.67	2.35	1.50	0	Fig. 7
B.A.	T-U difference	−1.0	+0.5	−1.0	+1.5	+2.0	
Case 102	Blood level (mg./L.)	3.75	3.15	2.50	1.50	0	Fig. 8
T.B.	T-U difference	0	+0.5	+0.5	+1.5	+1.5	

There are, however, several drawbacks in this method of expression which greatly diminish its applicability in clinical practice. First, where T and U fuse together to form one continuous curve, it is extremely difficult to identify whether the summit of the wave is formed by the T or U, or both, or whether the summit of the one is actually buried in one limb of the other. Second, when the T wave becomes diphasic, whether negative-positive or positive-negative, the T-U difference would be identical if only the positive part of the deflection of the T wave in either situation is being used for comparison with the U wave. Third, where the S-T, T, and U form a continuous sinuous curve, no apex or nadir of the T wave could be identified. Lastly, the difference between the height of the T and U wave could also be influenced by many extracardiac factors such as the distance of the heart from the chest wall, and presence of edema fluid in either pleural or pericardial cavity.[20]

In two patients (Cases 111 and 114) the U wave was upright during the course of quinidine therapy; it became inverted in Leads V_2 and V_4 after the quinidine level in blood had returned to zero, and remained so permanently afterwards (Figs. 13, 14). It must be presumed that U-wave inversion was originally present prior to quinidine administration, but was not identifiable owing to the atrial arrhythmia, and that quinidine changed the inverted U wave to a positive deflection. This effect of quinidine in changing an inverted U wave to an upright one is indeed very interesting, and has never been reported before in the literature.

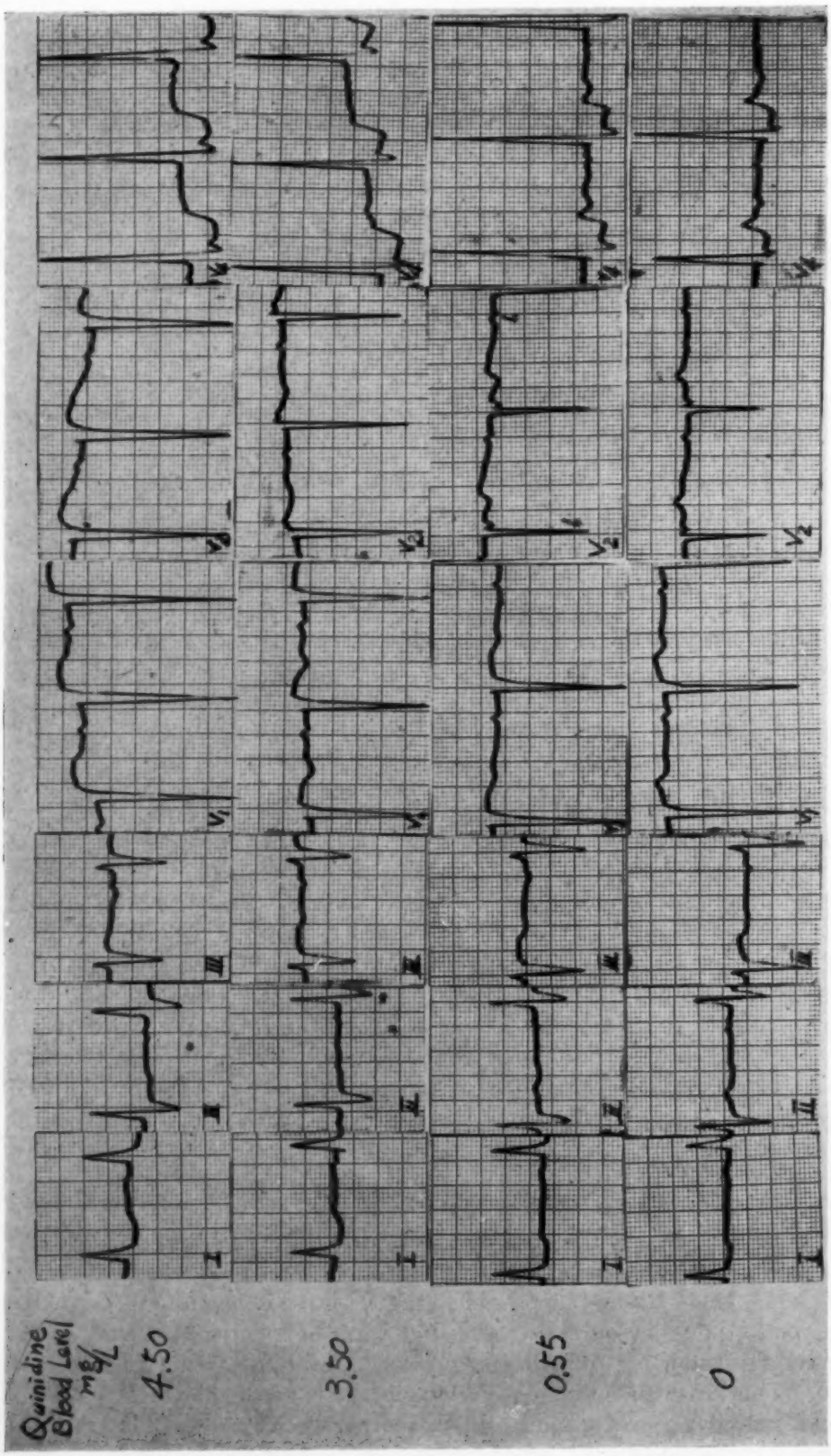

Fig. 13.—Case 111, W.G. Electrocardiograms showing the effect of quinidine on inverted U wave. In the last row, which can serve as the control, there is an inverted U wave in Leads V_2 and V_4. The effect of quinidine is seen in the upper three rows in which the U wave becomes upright in the same leads. Note also the typical changes in the S-T, T, and U in correlation with the blood levels of quinidine.

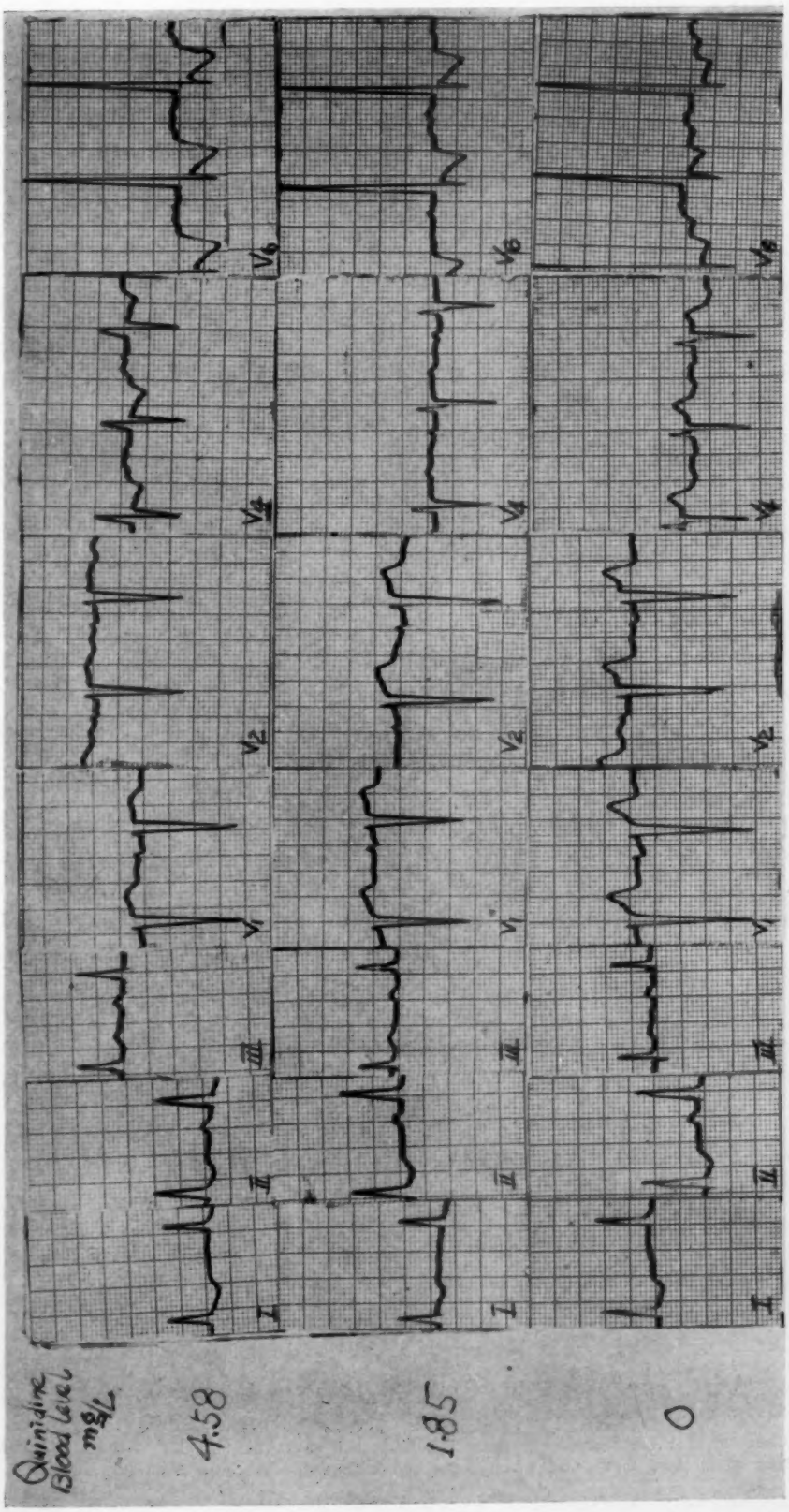

Fig. 14.—Case 114, O.K. Electrocardiograms showing the effect of quinidine on inverted U wave. In the last row, which can serve as the control, there is an inverted U wave in V_4 and V_6. The effect of quinidine is seen in the upper and middle rows in which the U wave becomes upright in the same leads. Note also the typical changes in S-T, T, and U at the peak level and as the blood level of quinidine declined.

Since all of our successfully converted cases received both digitalis and quinidine, the question arises whether this typical electrocardiographic pattern of the S-T, T-, and U-wave changes is due to quinidine alone, or a combined effect of quinidine and digitalis. We had the opportunity of observing one patient (Case 98) who showed the typical pattern of the discordant changes of the T and U wave after normal sinus rhythm was restored with both digitalis and quinidine (Fig. 15, rows *A*, *B*, *C*). Then both drugs were withdrawn and

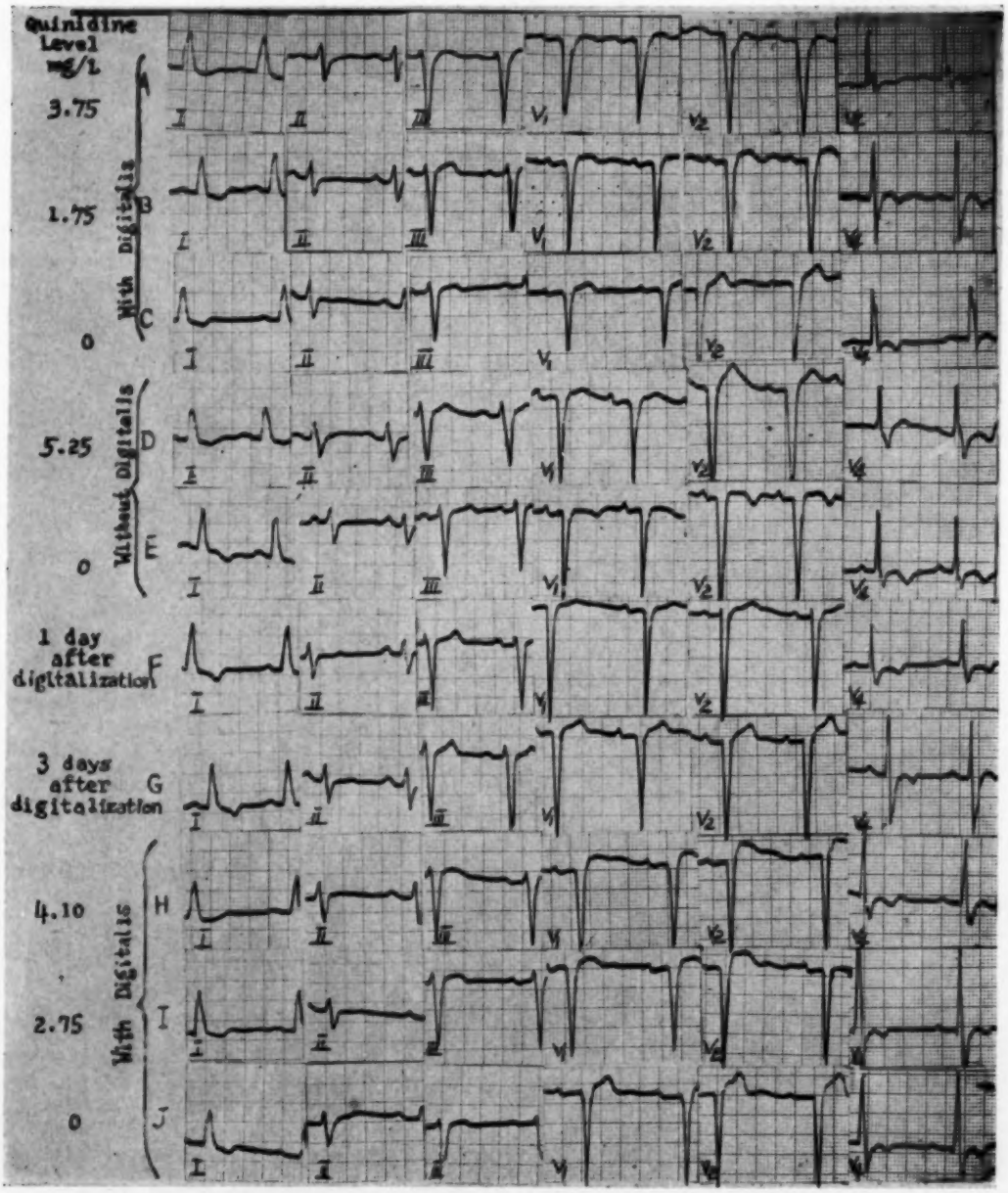

Fig. 15.—Case 98, P.F. Electrocardiograms showing the effect on the S-T segment, T and U wave of quinidine when used alone and when combined with digitalis. For discussion see text.

atrial flutter returned four weeks later. Quinidine was then administered without prior or simultaneous use of digitalis. At the peak blood level of quinidine of 5.25 mg. per liter, again the typical fusion of T and U wave with early "climbing-on" of the U wave was noted in Leads V_2 and V_4 (Fig. 15, row *D*). As the level of quinidine in blood declined toward zero, the T wave became inverted and the U wave also diminished in its amplitude as expected (Fig. 15, row *E*). The only difference between row *C* and row *E* of Fig. 15 was the elevation of the T wave in Leads V_1 and V_2, with a shortened Q-T interval in the former characteristic of digitalis effect. After digitalis administration, the electrocardiograms (Fig. 15, rows *F*, *G*) assumed the same pattern as in row *C;* that is, the T waves in Leads V_1 and V_2 became upright and the Q-T interval shortened. The quinidine was given again; the typical reciprocal changes of the S-T, T, and U wave were again observed (Fig. 15, rows *H*, *I*, *J*).

Therefore, we conclude that the typical electrocardiographic pattern showing the changes in S-T, T, and U wave is produced by quinidine alone. Digitalis may accentuate the changes in such a pattern. Papp[26] also showed that the U wave might be accentuated, or even produced, by digitalis alone; however, he noted no effect on the U wave after quinidine administration. Surawicz and Lepeschkin[20] also found examples of such an electrocardiographic pattern, identical with those observed by us in patients who were being treated at the same time with both digitalis and quinidine, and considered the combination of digitalis and quinidine necessary for the production of such a pattern. They also postulated that this digitalis-quinidine pattern might be due to a redistribution of intracellular and extracellular potassium, similar to that found in hypopotassemia, from which at times differentiation was almost possible.

It seems appropriate here to review briefly the subject of the U wave of the electrocardiogram. U wave has received little attention in the literature, apart from a condensed report in Lepeschkin's book.[9] It is not until recently that more significance has been given to the U wave, the general nature of which has been presented in a recent symposium.[27]

U wave is present in all normal subjects, and in nearly all patients.[9,21] They may reach 0.15 millivolt in the standard limb leads and 0.2 millivolt in precordial leads. Two conditions are essential for detection of the U wave; a sufficiently slow heart rate (not over 100), and the absence of atrial fibrillation.[28]

Negative U waves do not occur in normal electrocardiograms.[26,28,29,30] The inverted U wave may be the only electrocardiographic sign of a damaged heart[26]; it was seen in coronary thrombosis, angina pectoris, hypertension, aortic incompetence and pulmonary heart disease.[26,30] The U wave normally proceeds in the same direction as the preceding T wave; suspicion should arise whenever the rule of concordance of T and U waves seems invalid.[29]

Prominent U waves are found in bradycardia,[9] exercise,[9,26] athletes,[9,26] thyrotoxicosis,[26] hypertension,[9,26] dying heart,[9] hypopotassemia,[9,20,23] cerebral vascular accidents,[31] and digitalization.[9,26] Quinidine should be added to the above list of causes of a prominent U wave as a result of the present study.

Various theories about the pathogenesis of the U wave have been advanced:

1. Electrical expression of the function of aortic contraction (Hering[32]): It was definitely shown that this assumption was false, because in an electrocardiogram obtained directly from the aortic wall during pneumonolysis, no aortic wave was recorded.[33]

2. Dilatation potential (Maekawa[34]; Groedel and Miller[29]): Whether it can be explained as the biochemical result of muscular relaxation, or whether biochemical changes can only be explained on the basis of an active muscular process is open to discussion.[29]

3. After-potential during the supernormal recovery phase (Nahum and Hoff[28]; Segers[35]): As the U wave is found to coincide with the supernormal phase of ventricular excitability, most extrasystoles occurring during this wave, it is considered due to an after-potential similar to that of a nerve. The monophasic action potential of the frog's heart may actually be followed by a negative (that is, having the same direction as the monophasic action-potential) after-potential, corresponding to the supernormal phase.[35] However, Papp[26] challenged this theory; according to him, "the constant time relationship of U to the QRS complex, rather than with the T wave, and the fact that a mere change in heart rate makes it seem at one time systolic, and at another diastolic render doubtful the interpretation of U either as a wave arising from a muscle going out of contraction, or as the electrical expression of a supernormal recovery phase."

In the literature, there are reports on observations of the influence of drugs (digitalis, Adrenaline, norepinephrine, calcium, and many others) upon the U wave.[9,29,36] However, we have been unable to find any reference to the effect of quinidine on the U wave.

The typical electrocardiographic pattern produced by quinidine consists of a progressive depression of the S-T segment, lowering and/or inversion of the T wave, and increase in amplitude and premature take-off of the U wave in the mid-precordial leads. This pattern is rather constant and frequent in its occurrence during quinidine therapy. It is advocated that the electrocardiogram be employed to serve as a guide during quinidine therapy, in view of such a constant and parallel relationship of the particular electrocardiographic configuration to the blood level of quinidine. However, as shown before, the electrocardiographic change, as judged by the T-U difference, did not always bear a parallel relationship with the blood level of quinidine; this correlation is at best only an approximate one. This is explainable by the fact that high blood concentration may proceed, and much absorption by the myocardium and maximal myocardial level may occur after the peak blood level has passed.[37] Furthermore, the concomitant use of digitalis or other drugs might also influence the evolution of the electrocardiographic pattern. Finally, the same pattern found in two patients, or in the same patient on two different occasions, may occur at widely different blood levels of quinidine and may represent a considerably different degree of deviation from the initial pattern of these two patients. Thus the electrocardiogram more frequently and more reliably indicates the *existence* rather than the *degree* of quinidine effect. The electrocardiogram is a definite aid in the management of any patient receiving quinidine, particularly when measurement of blood level of quinidine cannot be obtained, provided the interpretations are made cautiously and are properly integrated with serial tracings.

SUMMARY

1. The electrocardiograms of 121 patients receiving quinidine for treatment of established atrial fibrillation and flutter were analyzed for the effect of

quinidine on the ventricular complex, with particular reference to the duration of the Q-T interval.

2. It was found that in 85 per cent of the successfully converted cases, the duration of the Q-T interval, corrected for the heart rate, is not prolonged. The widespread impression that Q-T is prolonged during quinidine administration has resulted from the inclusion of the U wave in the Q-T duration.

3. In 15 per cent of the cases receiving quinidine there was an actual prolongation of the Q-T duration, with or without notching of the T wave.

4. Methods for the differentiation of T-plus-U pattern in which the Q-T interval itself is not prolonged, from a true Q-T prolongation with or without notching of the T wave, are enumerated.

5. Quinidine changed an inverted U wave in two patients to a positive deflection.

6. A brief discussion of the U wave of the electrocardiogram was presented.

7. The typical electrocardiographic pattern in patients receiving quinidine is characterized by a depressed S-T segment and T wave opposite in polarity to a U wave of increased voltage, while the Q-T interval itself, corrected according to the heart rate, is in most cases normal in duration. This electrocardiographic pattern is produced by quinidine alone, although the simultaneous use of digitalis may accentuate the changes in such a pattern.

8. The electrocardiogram is a definite aid in the management of any patient receiving quinidine, particularly when measurement of the blood level of quinidine cannot be obtained. It is the change of the pattern rather than the pattern itself which is important for evaluation of the relative quinidine effect; the electrocardiogram more frequently and more reliably indicates the existence rather than the degree of quinidine effect.

SUMMARIO IN INTERLINGUA

Le exacte analyse del electrocardiogrammas de patientes sub tractamento a quinidina pro fibrillation e flutter atrial monstrava que in 85 pro cento del casos a conversion succedite il non ha prolongation del duration del intervallo Q-T post correction pro le frequentia cardiac individual. Le idea, frequentemente exprimite, que quinidina prolonga Q-T es le resultato del inclusion del unda U in le intervallo Q-T. Le configuration electrocardiographic que es typicamente producite per administrationes de quinidina se distingue per le depression del segmento S-T e del unda T e un exaggerate unda U in derivationes medi-precordial. Es etiam presentate un breve discussion del unda U.

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Clinical Reports

RUPTURED CONGENITAL ANEURYSM OF THE SINUS OF VALSALVA

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WE HAVE recently examined a young boy presenting the following problem: A continuous murmur, found at surgical exploration not to be due to a patent ductus arteriosus, with subsequent progressive heart failure. This report describes the eventual findings and, incidentally, adds another fatality to the list of contrast dye complications.

CASE REPORT

C.M., a 13-year-old white boy, was admitted to the University of Kansas Medical Center for the first time on March 23, 1954, in congestive heart failure.

A heart murmur was first noted at the age of 7, but the patient had no significant symptoms at that time. He was hospitalized elsewhere from February to April of 1953 for evaluation for possible rheumatic fever. During this hospitalization a patent ductus arteriosus was suspected because a continuous murmur was noted over the pulmonic area. Thoracotomy was done in July, 1953; this failed to reveal a patent ductus arteriosus and no definitive procedure was done. The patient then did fairly well until November, 1953, at which time his shortness of breath increased and peripheral edema appeared requiring hospitalization. Treatment consisted of low salt diet, digitalis, and mercurial diuretics, without significant improvement. He was then transferred to this hospital for further study.

Physical examination disclosed a pale, thin, white boy, with no cyanosis; Blood pressure: arm, 110/50-30 mm. Hg; pulse, 110 per minute. The carotid and subclavian arteries pulsated vigorously. A Grade 4 continuous thrill was palpated over the base of the heart. A Grade 5 harsh, machinery murmur was present at the base of the heart with the greatest intensity at the second left intercostal space. P_2 was louder than A_2 and markedly accentuated. The lungs were clear. The liver was palpable at four fingerbreadths below the right costal margin. There was marked ascites. The legs were edematous to the knees.

Urinalysis was negative; red blood cells, 5,320,000; hemoglobin, 13.4 Gm.; white blood cells and differential normal; sedimentation rate 4 mm. per hour; blood chemistry within normal limits; and hepatogram normal. Chest x-ray revealed diffuse cardiac enlargement, with pulmonary

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congestion. Cardiac fluoroscopy demonstrated enlargement of the pulmonary outflow tract, the left ventricle, left auricle, and the right ventricle. The aortic pulsations were very active. Right and left pulmonary arteries were pulsatile. Kymograph of the heart revealed active pulsations along both borders of the heart occurring in a normal manner. The electrocardiogram was suggestive of both right and left ventricular hypertrophy. (See Fig. 1.)

On admission the patient was placed on a low salt diet, Digitoxin 0.1 mg. daily, intermittent ammonium chloride and diuretics without significant improvement. Cardiac catheterization was performed with results as tabulated (Table I and Fig. 2).

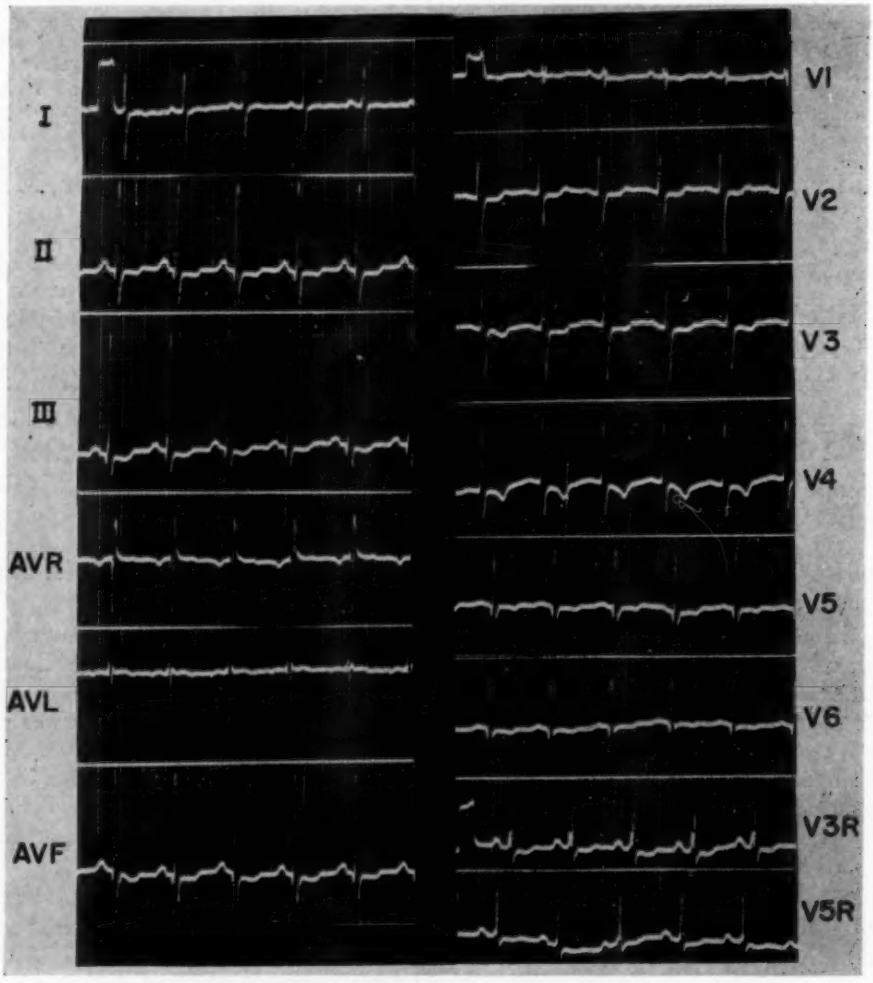

Fig. 1.—Admission ECG showing sinus tachycardia, combined ventricular hypertrophy, and myocardial ischemia.

On April 1, 1954, a retrograde aortogram was performed through a cardiac catheter with its tip advanced from the left radial artery to the aortic arch. Skin test for sensitivity to Urokon was negative. Both common carotid arteries were occluded by external pressure for approximately 8 seconds at the time of injection of the dye. Approximately 5 seconds after injection of 8 c.c. of 70 per cent Urokon, the patient developed rigidity of the arms and legs followed by unconsciousness and cyanosis. No respiratory changes or hypotension were noted at this time. Twenty minutes after the injection, the patient developed bilateral nystagmus and blood pressure was found to be 210/0 mm. Hg. The patient received continuous oxygen. A stellate ganglion block was performed two hours after the injection without improvement in the patient's condition. Blood

pressure at this time was 185/40-0 mm. Hg. The bilateral nystagmus persisted for approximately four hours. Four hours following the injection, the machinery murmur changed into a to-and-fro murmur at the pulmonary area. The blood pressure was found to be 90/30-30 mm. Hg. The drop in blood pressure was thought to account for the change from a continuous murmur into a to-and-fro murmur. The pupils were dilated and fixed and the patient had Babinski

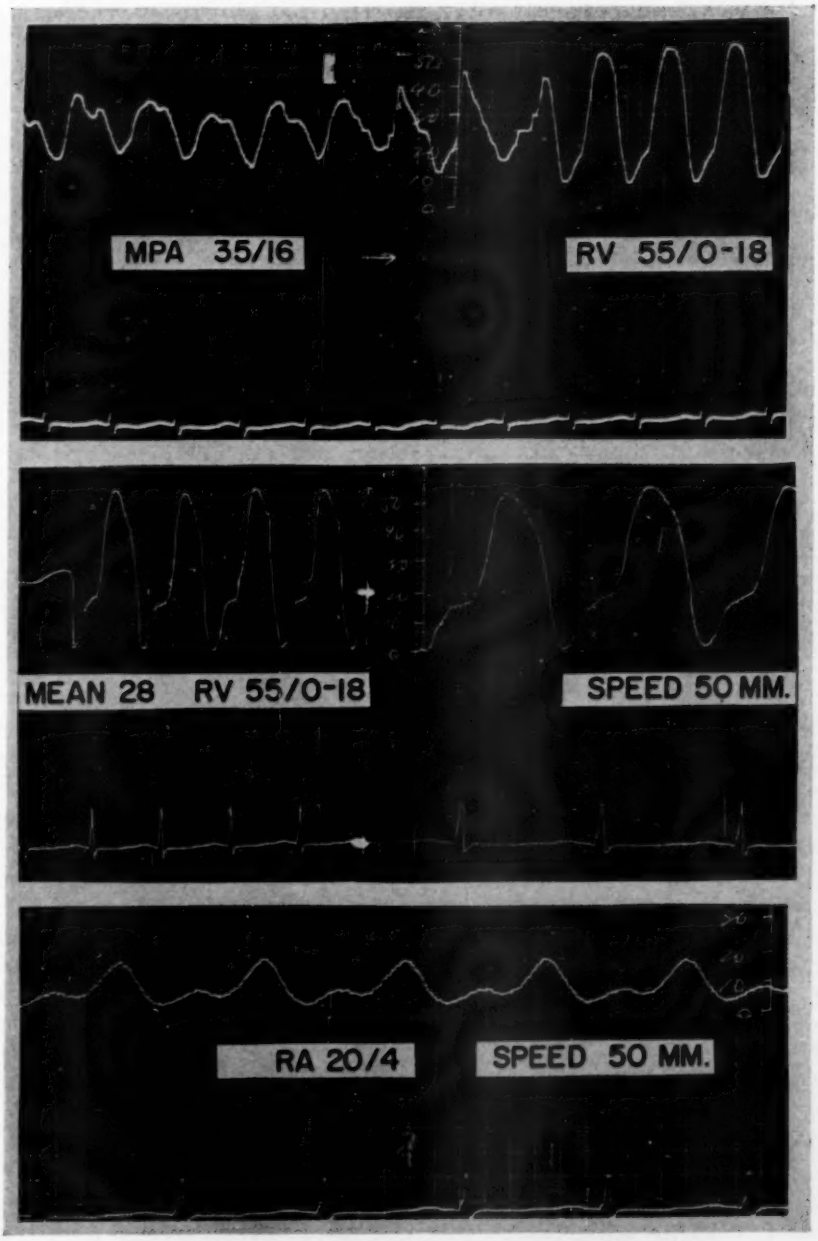

Fig. 2.—The upper tracing showing the continuous pressure record from main pulmonary artery (MPA) to right ventricle and demonstrating slight pressure gradient between main pulmonary artery and right ventricle; the middle tracing showing right ventricular (RV) pressure in different speeds with elevation of end diastolic pressure; the lower tracing showing right auricular (RA) curve with prominent V waves.

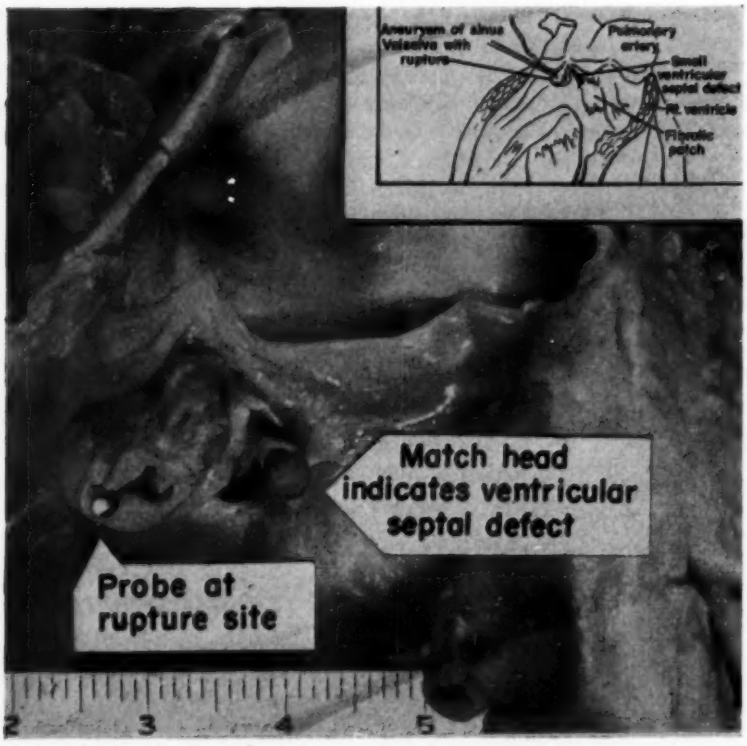

Fig. 3.—View of interior of right ventricle, at the outflow tract, demonstrating the ruptured aneurysm and the small septal defect.

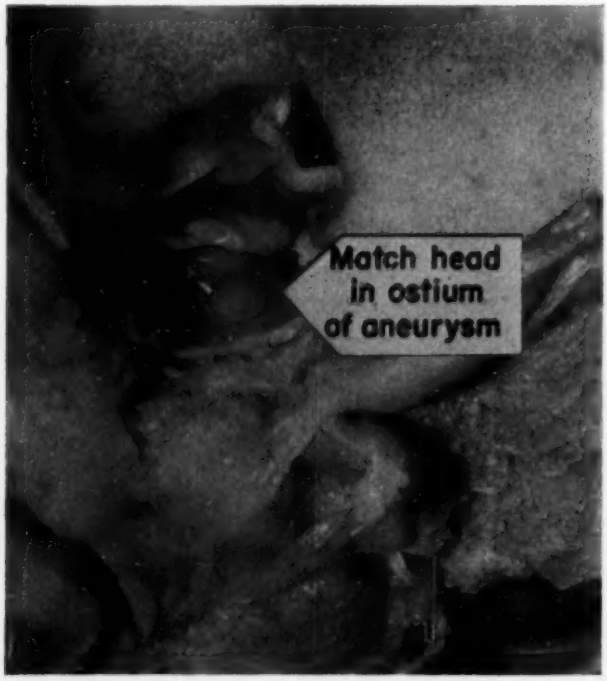

Fig. 4.—View from above, looking at the aortic valve and demonstrating site of right coronary sinus of Valsalva with match through the rupture.

reflexes. He remained in a comatose state with dilated, fixed pupils and expired in a state of circulatory collapse on April 5, 1954, in spite of supportive measures. The angiogram revealed no retrograde filling of the heart.

TABLE I

LOCATION OF SAMPLE	INFERIOR VENA CAVA	RIGHT AURICLE		RIGHT VENTRICLE		PULMONARY ARTERY			FEMORAL ARTERY	OXYGEN CAPACITY
		INFLOW	OUTFLOW	INFLOW	OUTFLOW	MAIN	RIGHT	LEFT		
O_2 content (vol. %)	11.7	8.3	10.9	13.3	14.8	14.5	14.5	14.8	16.6	16.9
O_2 saturation (%)	69.2	49.1	64.5	78.7	87.6	85.8	85.8	87.6	98.2	100
Pressure (mm. Hg)		24/4		55/0–18		35/15			100/50–30	

The increased right auricular pressure and end diastolic pressure in the right ventricle indicate right heart failure. The markedly increased oxygen content in the right ventricle indicates a large L-R shunt at the right ventricular level. The slight pressure gradient between the main pulmonary artery and the right ventricle is probably explained on the basis of the partial obstruction of the pulmonary outflow tract from the dilated aneurysm and the great magnitude of the pulmonary flow.

AUTOPSY

Heart.—The pericardium was densely adherent to epicardium. The heart was markedly enlarged, weighing 540 grams. This enlargement was predominantly of the right auricle and right ventricle. In the right coronary sinus of Valsalva near the anterior commissure, there was a diverticulum which protruded into the pulmonary conus just below the right cusp of the pulmonary valve. This diverticulum measured 15 by 12 mm., with its ostium measuring 8 mm. in diameter. At the tip of the diverticulum there was an opening 4 mm. in diameter (Fig. 3). There was an interventricular septal defect measuring 3 by 5 mm. just below the right and middle cusps of the pulmonary valve (Figs. 3 and 4). In the floor of the pulmonary conus opposite the opening of the diverticulum there was an irregular endocardial thickening. The coronary arteries were normal. Histologic section showed no evidence suggesting a rheumatic lesion.

Brain.—The brain was exceedingly soft and friable, particularly the right temporal and occipital lobes. The right thalamus, the pons and brain stem, and the cerebellum showed extensive necrosis and hemorrhage. The zone of necrosis appeared to correspond directly with the distribution of all branches of the basilar artery with the exception of the right posterior cerebral artery. Histologic examination revealed an extremely diffuse necrosis in the affected areas characterized by edema, perivascular hemorrhages, and generalized neuronal necrosis. The necrosis was spotty and affected primarily the small vessels. Section through the middle and anterior cerebral arteries showed only questionable damage.

Chronic passive congestion of the lungs, cardiac cirrhosis of the liver, and thrombosis of the left radial and brachial arteries were also present.

DIFFERENTIAL DIAGNOSIS

The differential diagnostic possibilities rest primarily with cardiac conditions producing continuous murmurs and congestive heart failure. A continuous murmur is one which begins with the first heart sound and continues throughout systole and diastole. It is frequently accentuated during systole extending on into diastole, occasionally fading out of perceptible auditory range. It is not to-and-fro.

1. *Patent Ductus Arteriosus and Aortic Septal Defect.*—In the absence of a known history of sudden onset of the continuous murmur, the differentiation between patent ductus arteriosus, aortic septal defect, and congenital coronary sinus aneurysm is difficult. Cardiac catheterization may be of value in revealing a left-to-right shunt at the pulmonary artery level in patent ductus arteriosus and aortic septal defect, as contrasted with a left-to-right shunt at the right ventricular or right auricular level in a ruptured sinus of Valsalva. Congenital aneurysms of the sinuses of Valsalva may rupture into the pulmonary artery and, in such case, cardiac catheterization would be of no differential value, although no case has been reported. Aortography, in demonstrating the passage of opacified blood from the aorta into the pulmonary artery in aortic septal defect and through a patent ductus into the pulmonary artery, should be of differential value. In the case of ruptured sinus of Valsalva the opacified blood would escape from the aorta into the right auricle or right ventricle. Patent ductus arteriosus or aortic septal defect plus pulmonary regurgitation would be extremely difficult to differentiate from a ruptured coronary sinus aneurysm into the right ventricle.

2. *Ventricular Septal Defect Including Eisenmenger's Complex.*—A high ventricular septal defect may occasionally produce a continuous thrill and murmur. Hurst and Schemm,[1] and Morgan and Burchell[2] have reported cases of ventricular septal defect with continuous murmurs. The defect in the septum may not support one leaf of the aortic valve resulting in aortic insufficiency. Ventricular septal defect has been noted to be a frequent accompanying lesion in aneurysms of the sinuses of Valsalva.[3,4] For this reason the demonstration of ventricular septal defect by catheterization is of little value in differential diagnosis. Differentiation between ventricular septal defect with aortic regurgitation and ruptured sinus of Valsalva may be difficult and would depend upon the observation of the sudden onset of a continuous murmur, as is characteristic of rupture of an aneurysm of the sinuses of Valsalva.

3. *Pulmonary Arteriovenous Aneurysm.*—A continuous murmur is frequently associated with pulmonary arteriovenous aneurysms. When the aneurysm is superficial and located in the left superior lobe, difficulty may arise in differentiating it from a ruptured sinus of Valsalva. The murmur of pulmonary arteriovenous fistula is seldom so loud and harsh as that of a ruptured sinus of Valsalva. The murmur in the former may disappear completely on deep expiration or with the Valsalva maneuver. The systolic accentuation is usually less prominent in the pulmonary arteriovenous aneurysms. An angiogram will usually outline the arteriovenous aneurysm and should serve to differentiate the two lesions. Pulmonary arteriovenous aneurysms usually result in cyanosis with digital clubbing and polycythemia, or occasionally hemoptysis. Infrequently the pulsating pulmonary arteriovenous aneurysm may be seen at fluoroscopy. The lesion does not burden the heart and, therefore, the electrocardiogram is normal and decompensation does not occur.

4. *Arteriovenous Fistula of the Chest Wall.*—Chest wall arteriovenous fistula may be congenital or may develop secondary to trauma, such as rib fracture or stab wound. A continuous murmur is produced which might be confused with

a ruptured sinus of Valsalva on occasion, if properly located. The superficial character of the thrill and murmur in the chest wall is of diagnostic value and should be of differential significance. Special procedures may be necessary in differentiation of these two lesions. We have recently seen a patient with a continuous murmur in the first and second left intercostal space, and in whom the murmur was iatrogenic as a result of surgical anastomosis of the left subclavian artery and the left innominate vein.

5. *Bronchial Collateral Circulation.*—Extensive collateral circulation by way of the bronchial arteries, such as is seen in pulmonary atresia or truncus arteriosus, may produce a continuous murmur. This murmur is more widely distributed over the chest and should not present a problem in differential diagnosis.

6. *Venous Hum.*—A loud venous hum may be well transmitted to the base of the heart. However, it results in no disturbance in hemodynamics, and obliteration of the neck veins eliminates the murmur.

7. *Rupture of a Normal Sinus of Valsalva Due to Bacterial Endocarditis.*—An exactly similar picture of acute onset of cardiac failure and continuous murmur may result from the destruction of an otherwise normal sinus by infection.

8. *Syphilis of the Root of the Aorta With Aneurysm of the Sinus of Valsalva.*—A disappearing cause of aneurysm of the sinus of Valsalva is syphilis. Rupture of such an aneurysm can occur, with a subsequent continuous murmur, collapsing pulse, and congestive failure.

9. *Miscellaneous.*—Among the conditions which must be considered in differential diagnosis are anomalous pulmonary venous drainage,[5] aortic stenosis and regurgitation, congenital aneurysmal dilatation of the aorta with regurgitation, aortic aneurysm with rupture into the pulmonary artery, substernal thyroid, and coronary anteriovenous fistula.[6]

ETIOLOGY

Congenital aneurysm of the coronary sinus of Valsalva is a rare anomaly. To date, only thirty-four cases have been reported. In these thirty-four cases, twenty-five developed in the right coronary sinus, four from noncoronary sinus, four from all three sinuses, and only one from the left coronary sinus. The embryological causes of this defect are probably failure of fusion between the proximal and distal bulbar swellings and developmental defect of the elastic tissue of the base of the aorta, or a combination of these conditions.[3,4,7,8] This occurs in the seventh week of development.[9]

DISCUSSION

A definite clinical diagnosis was not established prior to death in this patient. Patent ductus arteriosus had been eliminated by previous surgery, and the differential diagnosis was felt to rest between an aortic septal defect and rupture of a congenital sinus of Valsalva aneurysm. As a result of cardiac catheterization, the latter was felt to be the more likely diagnosis, but it was impossible to rule out aortic septal defect with pulmonary regurgitation.

Diagnosis of a coronary sinus aneurysm prior to rupture is difficult as the symptoms, if present, are not specific. Cardiac arrhythmias may be present, perhaps as a manifestation of pressure exerted on the cardiac conduction system by the aneurysm. Falhout and Thompson[7] have reported a case of unruptured congenital aneurysm of the right sinus of Valsalva diagnosed by aortography.

Rupture is occasionally accompanied by severe substernal pain and dyspnea.[10] As the shunt is from left to right, cyanosis is usually absent in the uncomplicated case. The usual site of rupture is into the right ventricle and less commonly, the right auricle. Following this, there is commonly rapid onset of left and right ventricular failure as evidenced by dyspnea, ascites, dependent edema, and combined ventricular enlargement. The radial pulse is of a collapsing character, and a loud machinery or to-and-fro murmur appears at the base of the heart, usually maximal in the second and third intercostal spaces near the sternum. This is often accompanied by a thrill in the same area. Occasionally, only a systolic murmur will be present. In the terminal stage as the systemic pressure drops the continuous murmur may change into a to-and-fro murmur. This occurred in our patient. The rupture may occur from sinus to right auricle and from sinus to right ventricle.

Fluoroscopy may be of considerable value. The aorta and left ventricle commonly show active pulsation associated with enlargement and active pulsation of the main pulmonary segment and its secondary branches. The degree of pulmonary and aortic pulsation is usually correlated with the magnitude of the shunt. There is also generalized cardiac enlargement.

Cardiac catheterization may be of considerable value in determining the location and amount of the shunt, although a part of the shunt may be due to the frequently associated lesion of a ventricular septal defect. In the only previously reported case in which cardiac catheterization was performed, the technique was not helpful as the aneurysm had not ruptured.[7]

The electrocardiographic changes are nonspecific and consequently of little value in differential diagnosis. Normal electrocardiogram right and left axis deviation, bundle branch block, auricular fibrillation, and complete heart block have all been reported.[3,4,10]

Death is usually the result of progressive congestive heart failure. A few cases have developed complicating subacute bacterial endocarditis.[10] Rarely, a fatality may result from cardiac arrhythmia or heart block as a result of a disturbance of the conduction system.[3] Sudden death has been reported at the time of rupture of the aneurysm.[11]

Although this case would undoubtedly have progressed to a fatal termination as a result of the intractable congestive failure, the death must be attributed to arteriography. Contrast media used was 70 per cent Urokon and preliminary testing revealed no evidence of sensitivity. Bilateral carotid artery pressure was applied for approximately 8 seconds during injection of the dye. In spite of this the patient developed almost immediate evidence of severe central nervous system injury. Apparently the dye entered the basilar arteries via the vertebral arterial route. Reactions of this type have been reported. Deterling[12] reported one fatality using 50 per cent Urokon and two cases of immediate tran-

sient aphasia and hemiplegia. Helmsworth and associates[13] reported one death after using 70 per cent Diodrast and, in two other patients, 75 per cent Neo-Iopax produced a transient convulsion in one and excitation in the other. The procedure in all of the above cases was arteriography.

Broman and Olsson[14] reporting on the tolerance of cerebral blood vessels to contrast media of the Diodrast type in cerebral angiography, demonstrated injury and impairment of the blood brain barrier. This consisted of stasis and punctate hemorrhages and was thought to be the result of osmotic action and chemotactic effect.

Post-mortem examination in this case revealed massive encephalomalacia, necrosis, and hemorrhage, which were probably the result of entrance of 70 per cent Urokon into the cerebral vessels with breakdown of the blood brain barrier. Bilateral carotid artery occlusion during injection was of no protective value.

THERAPY

To date, therapy in this condition has consisted of routine methods of treatment of the congestive heart failure which follows the rupture of the aneurysm. Hypothermia or cross-circulation techniques permitting open-heart surgery suggest the possibility of repair in the future.

SUMMARY

1. Report is made of a case of congenital aneurysm of the right coronary sinus of Valsalva with rupture into the outflow tract of the right ventricle, and death as a complication of aortography.
2. Cardiac catheterization data are presented.
3. Differential diagnosis and embryology are discussed.
4. A review of the probable mechanism of death is presented.

SUMMARIO IN INTERLINGUA

1. Es reportate un caso de congenite aneurysma el dextere sinus coronari de Valsalva con ruptura a in le via efferente ex le ventriculo dextere, sequite per morte como complication de aortographia.
2. Es presentate datos de catheterisation cardiac.
3. Es discutite le problemas del diagnose differential e del embryologia.
4. Es presentate un revista del mechanismo que probabilemente effectuava le morte del patiente.

We wish to express our thanks to Drs. Don Carlos Peete, John Mayer, Wayne Hart, and Roswith Lade for referring this patient to us.

The autopsy was performed by Dr. George Gould, Department of Pathology, University of Kansas Medical Center, Kansas City, Kan.

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SPONTANEOUS REVERSION OF VENTRICULAR FIBRILLATION TO NORMAL SINUS RHYTHM IN A CASE OF ACUTE MYOCARDIAL INFARCTION

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VENTRICULAR fibrillation is the terminal cardiac mechanism in about 50 per cent of the patients dying from coronary occlusion.[1] Spontaneous recovery following ventricular fibrillation has been documented in Stokes-Adams attacks[2-4] and after exertion or induced anoxia in cardiac patients.[5,6] However, there are few documented cases where recovery occurred following a myocardial infarction.[7] The purpose of this paper is to report a case of spontaneous conversion of an episode of ventricular fibrillation to a normal sinus rhythm in the presence of an acute myocardial infarction.

CASE REPORT

E. W., a 61-year-old white housewife, was admitted to the Graduate Hospital of the University of Pennsylvania on Feb. 5, 1955, because of frequent severe episodes of substernal and precordial chest pain of about one week's duration. Family history disclosed that two siblings had died in their late forties of "heart attacks" and the patient's grandmother had high blood pressure. The past medical history revealed that she had the usual childhood diseases without sequela. She had a hysterectomy in 1930 and a bilateral oophorectomy in 1933. In 1948, she was hospitalized for bronchopneumonia. The history of present illness dated back to 1940 when the patient first learned she had high blood pressure. She was fairly well except for an occasional episode of chest pain brought on by exertion, slight ankle edema, and mild dyspnea on exertion. Digitalis had been started in 1945 and the patient continued on 1½ grains of the whole leaf daily. She had apparently also received parenteral mercurial diuretics intermittently since 1948. In February, 1951, a sudden occlusion of the terminal aorta in the region of the bifurcation with extension into the right ileo-femoral artery resulted in a right mid-thigh amputation. Her postoperative convalescence was uncomplicated. For a period of several months after returning home, the patient was able to remain ambulatory with the aid of crutches and performed a few of her household duties. Most of the day, however, she spent sitting in a chair or lying propped up in bed. Exertional dyspnea and chest pain became more troublesome and her activity gradually diminished.

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One week prior to admission, the patient experienced a severe crushing, constrictive precordial chest pain associated with marked dyspnea and palpitation; the pain lasted about one hour and then slowly subsided. Four days before hospitalization she again had severe substernal pain which now radiated to the left shoulder and down the left arm; after forty-five minutes this was relieved by an injection. She experienced a third episode of left chest pain with radiation to the left shoulder and down the left arm two days prior to entering the hospital. Following this, she developed a continuous sensation of substernal oppression.

On admission to the hospital, her blood pressure was 140/90 mm. Hg (compared with her usual pressure of 170/110 mm. Hg); the pulse rate was 108 per minute and regular, and respirations were 22 per minute. Bilateral basilar râles were present. The heart was enlarged to the left on percussion; a regular rhythm was present. Heart sounds were distant and a Grade 3 aortic systolic murmur was present. The liver was not palpable. There was 1+ sacral pitting edema; no pretibial or ankle edema was detected in the left leg. An electrocardiogram, on admission, showed an acute posterolateral myocardial infarction (Fig. 1). While the resident was questioning the patient regarding the details of her present illness, she developed sudden convulsive movements, became cyanotic, and went into sudden collapse during which no pulse or

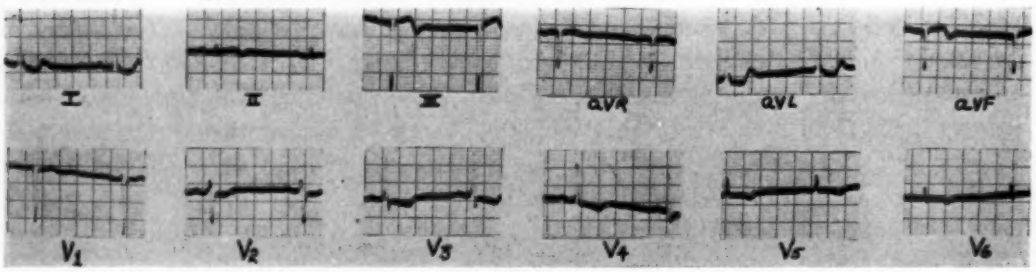

Fig. 1.—Electrocardiogram on admission to the hospital showed depression of the S-T segment in Lead I, elevation of the segment in Leads III and aV_F, and inversion of the T waves in these leads. There is inversion of T_2, $V_{3,4,5,6}$. These findings confirmed the clinical impression of an acute myocardial infarction which probably involved the posterolateral wall.

respirations were present. She apparently was dead. Two minutes later she developed a gasping-type of respiration with about 3 to 4 gasps per minute. The electrocardiographic machine, which was near the bed, was then quickly connected. The electrocardiogram showed ventricular fibrillation (Fig. 2). While the nurse ran for a long needle, through which Pronestyl might be given into the heart, an attempt at intracardiac puncture with a 1¼ inch long No. 20 intravenous needle was performed unsuccessfully: no blood could be aspirated. Twenty seconds later the electrocardiogram showed disappearance of the ventricular fibrillation, the pulse again became palpable, and the blood pressure was recorded at 100/50 mm. Hg. Oxygen by nasal catheter was then started (about ten minutes after onset of the ventricular fibrillation) and continued at 6 liters per minute. The patient remained stuporous for a period of about twenty minutes after restoration of the pulse. Subsequently, awareness gradually returned over a period of twelve hours. On the following day, and for the first week of her hospital stay, she complained of frequent episodes of severe substernal chest pain. She was treated with moderately heavy doses of Demerol (to relieve the chest pain) and anticoagulants. No antifibrillatory drugs were administered during the period in the hospital; digitalis (which the patient had taken for seven years) was withheld. She remained in the hospital for fifty-three days. Though more protracted than usual, her convalescence was without further complication, and on March 30, 1955, she was discharged free of pain and ambulatory with the aid of crutches. She had a complete amnesia for all that transpired during the first twenty-four hours of hospitalization. Detailed questioning failed to reveal any other evidence of memory loss or mental deterioration. The patient's husband was unable to detect any abnormality in cerebration.

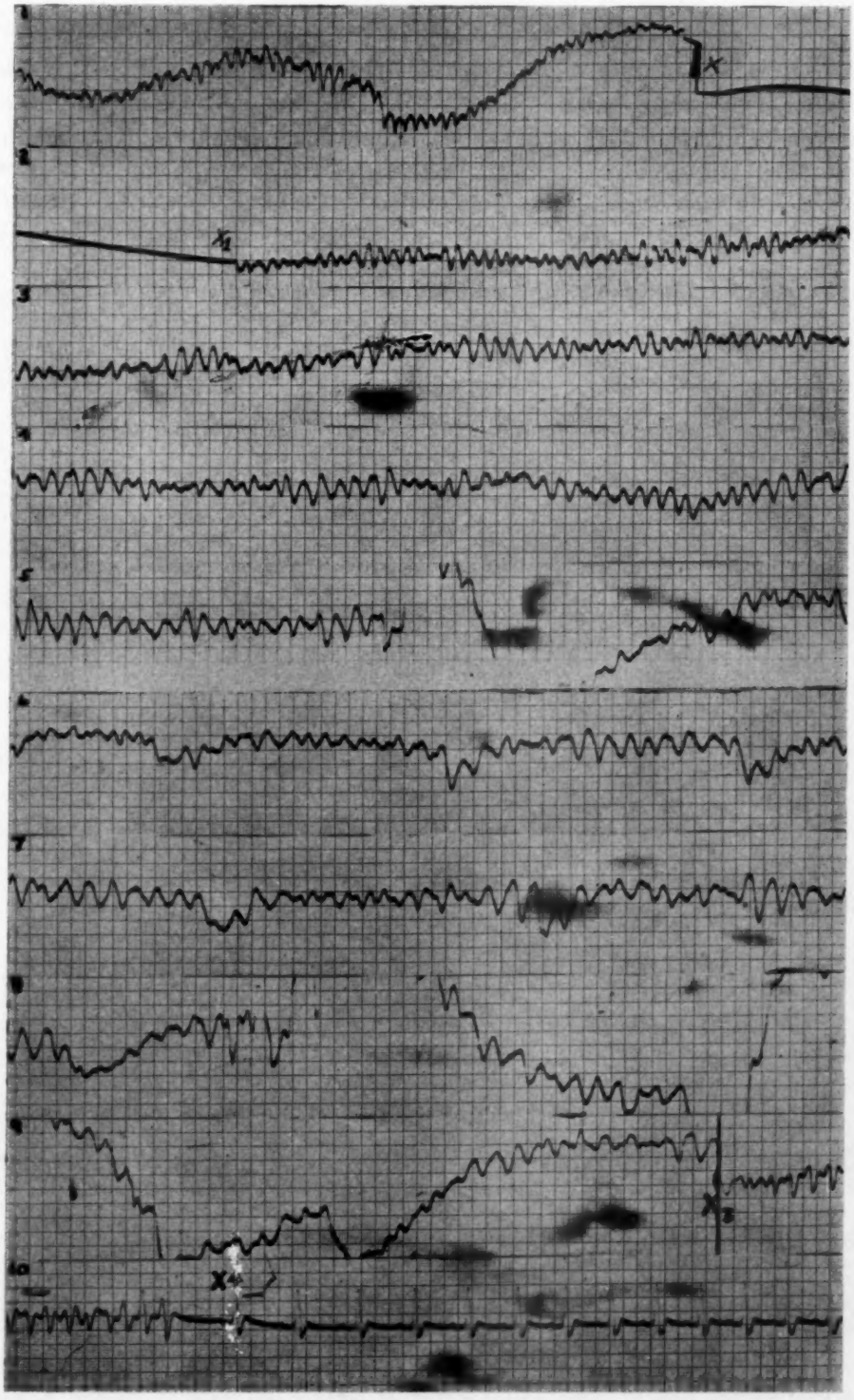

Fig. 2.—Strips 1 through 10 represent a continuous tracing recorded 3 to 4 minutes after the patient developed sudden circulatory collapse. X to X_1 is an artifact resulting from elevating the instamatic button. Ventricular fibrillation is recorded for 1 minute and 47 seconds. At X_2 the machine was stopped for the attempted cardiac puncture. Four seconds after starting the machine spontaneous reversion of the ventricular fibrillation to a sinus rhythm is recorded. At X_4 a gradually increasing sinus rhythm develops with a rate of 100 per minute at the end of the strip. The P-R interval is prolonged to 0.24 second.

DISCUSSION

It is of some interest to discuss the influence of cardiac puncture on the conversion of the ventricular fibrillation to a normal mechanism, in the event the needle reached the myocardium. First, mechanical stimulation of the heart, e.g., manual compression, is rarely successful in converting ventricular fibrillation, either in man or in the experimental animal, if it is performed without the aid of electrical defibrillation and/or drugs.[8,9] Moreover, in those cases of termi-

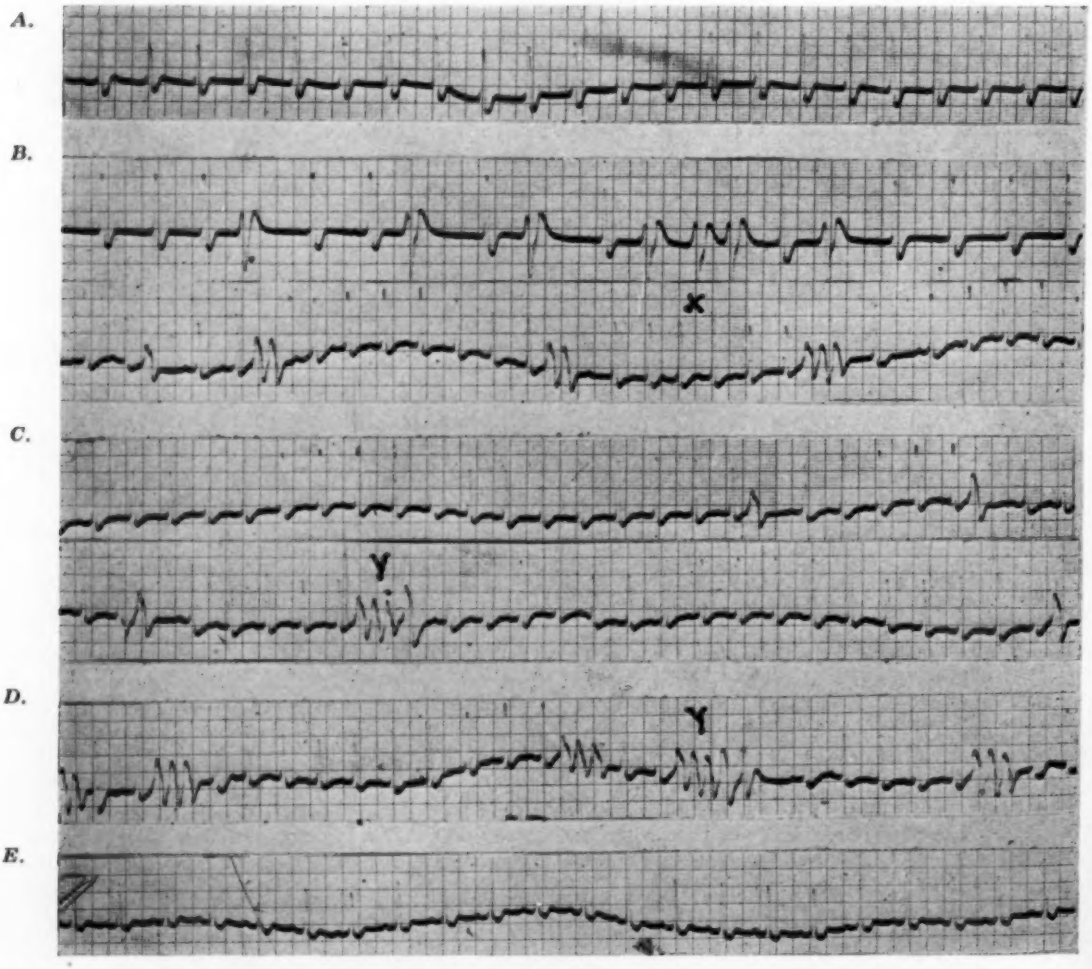

Fig. 3.—The transitory period from ventricular fibrillation to an established sinus rhythm required 4 to 5 minutes. *A*, Nodal tachycardia is present, with a ventricular rate of 100 per minute. *B*, Note multiple multifocal ventricular contractions. At X a short run of auricular extrasystoles are recorded. *C* and *D*, Note short paroxysms of ventricular tachycardia at Y. *E*, Two minutes after *D*, sinus rhythm is established with a ventricular rate of 110 per minute. The P-R interval measures 0.18 second.

nal cardiac arrest and in ventricular asystole associated with complete A-V heart block, the mechanical stimulation afforded by cardiac puncture generally elicits an immediate electrical response, if the heart responds at all. Occasionally, normal cardiac beating may be restored by this procedure. In our patient, the

reversion from ventricular fibrillation was delayed about twenty seconds. It therefore appears most likely that this reversion of the ventricular fibrillation was spontaneous.

The period of conversion from ventricular fibrillation to an established sinus rhythm required four to five minutes. During this period of time, the following electrocardiographic changes were observed. The ventricular fibrillation was followed immediately by a short run of ventricular tachycardia, and then by an alternating sinus, auricular and nodal rhythm with and without first degree A-V heart block accompanying the supranodal contractions. Frequent short episodes of ventricular tachycardia also were observed (Fig. 3).

SUMMARY

A 61-year-old white woman presented a history of advanced vascular disease of approximately fifteen years' duration, resulting from hypertensive and arteriosclerotic cardiovascular disease. Following an acute posterolateral myocardial infarction, she went into sudden collapse lasting approximately five minutes. Ventricular fibrillation was actually recorded over a period of 1 minute and 47 seconds and then spontaneously reverted to a normal sinus rhythm. Her convalescence was uneventful and she was discharged without any evidence of cerebral deterioration.

SUMMARIO IN INTERLINGUA

Un femina blanc de 61 annos de etate presentava un historia de avantiate morbo vascular de un duration de circa 15 annos, resultante ab hypertensive e arteriosclerotic morbo cardiovascular. Post acute infarcimento myocardial posterolateral, illa habeva un subitanee collapso que durava circa cinque minutas. Fibrillation ventricular esseva de facto registrate pro 107 secundas. Postea illo reverteva spontaneemente al normal rhythmo sinusal. Le convalescentia procedeva sin complication. Le patiente esseva dimittite sin ulle indicio de deterioration cerebral.

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SUCCESSFUL TREATMENT OF VENTRICULAR ARREST DURING COMPLETE HEART BLOCK BY EXTERNAL ELECTRICAL STIMULATION

A Case Report

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THE literature and rationale of the use of an artificial cardiac pacemaker for the treatment of Stokes-Adams Syndrome has been reviewed in an article appearing elsewhere in this JOURNAL.[1]

The following case, in which this apparatus was used for a prolonged period with subsequent recovery, confirms further its value in the treatment of ventricular arrest.

CASE REPORT

G.W., No. 568-55, a 79-year-old white man, was admitted to the hospital for the first time on May 2, 1955, with congestive heart failure. He had been in good health until three weeks before admission when dyspnea, dependent edema and cough with expectoration of mucoid sputum were noted. These had become progressively worse. Other symptoms experienced were anorexia, and weight loss of 20 pounds. Chest pain had never been present.

Physical examination on admission revealed a fairly well-nourished, alert man with some orthopnea. The temperature was 97° F., pulse 48, and respirations 35 per minute. The blood pressure was 230/70 mm.Hg, the venous pressure was elevated and prominent pulsations were noted occasionally in the neck veins. Bilateral pleural effusions were present with râles in the dependent parts of both lungs. The heart appeared enlarged, the rhythm was slow and regular, no murmurs were audible, but auricular sounds were heard. The liver was enlarged but the spleen could not be felt. Moderate sacral and pedal edema was present. Incidental findings included cervical adenopathy, a large inguinal hernia, and a basal cell carcinoma of the scalp.

The pertinent laboratory findings were a hemoglobin of 11.0 Gm. per cent, a white-cell count of 16,050 per cubic millimeters with 62 per cent small lymphocytes. Subsequent investigation confirmed the presence of chronic lymphocytic leukemia. Urinalysis showed proteinura of 64 mg. per cent and occasional red and white cells. The electrocardiogram on May 3 revealed complete auriculoventricular dissociation with a ventricular rate of 48 and an auricular rate of 75 per minute. A chest x-ray showed slight cardiac enlargement together with pulmonary congestion and bilateral hydrothorax.

The patient had received no therapy before hospitalization. On admission, he was placed on bed rest, moderate sodium restriction, and Thiomerin, 2 c.c. subcutaneously daily for four days, then thrice weekly. A thoracentesis was performed shortly after admission and 2,000 ml. of straw-colored fluid was removed.

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On the second hospital day, an episode of unconsciousness occurred associated with clonic convulsive movements and stertorous breathing. This was not observed by the house officer. It lasted a few minutes and was followed by unconsciousness for two hours. Following this episode, the pulse rate was 50 per minute. Neurological examination was normal and complete recovery ensued.

During the next seven days, the signs of congestive heart failure lessened markedly. On the fifth hospital day, the patient was given Digoxin 0.25 mg. twice daily by mouth for a total of 1.5 mg. This medication was then discontinued because of slowing of the ventricular rate to 33 beats per minute.

On the ninth day, commencing at 2:30 P.M., the patient developed a series of eight consecutive Stokes-Adams attacks during a three-hour period. Each lasted 15 to 20 seconds and was characterized by the loss of consciousness, convulsive movements, stertorous breathing, and an imperceptible pulse. The electrocardiogram showed ventricular asystole during the attacks and a ventricular rate varying between 12 and 32 beats per minute between them. He was treated with oxygen, ephedrine 3/8 grain, atrophine 1/100 grain, and Adrenalin 0.66 ml. of 1:1,000 solution subcutaneously. No improvement was seen. At 5:10 P.M., the external electric pacemaker* was applied. The minimal effective amplitude was 50 volts. Impulses were delivered at a rate of 60 per minute. With lesser amplitude, seizures were not prevented. Subsequently, stimulation by the pacemaker for the next thirty-one hours was necessary. This was continuous except for nine interruptions varying between 5 and 117 minutes in length and totaling five hours in all. Ventricular contractions occurred during these times but were not sustained. During this period, the longest single application was seven hours. (Fig. 1.)

Concomitant therapy included continuous intravenous infusion of Adrenalin, 4 ml. of 1:1,000 solution in 1,000 ml. of 5 per cent glucose and water at 15 drops per minute as recommended by Zoll.[2]

On the tenth hospital day, while the pacemaker was functioning, 25 mg. of ACTH was given intravenously and repeated the following day.

From midnight on the eleventh hospital day until 9:10 A.M. on the twelfth day, a total of 9 hours and 10 minutes, regular ventricular contractions at a rate of 38 to 42 per minute occurred. Sudden spontaneous ventricular arrest again ensued, accompanied by a Stokes-Adams attack. This was immediately terminated by the cardiac pacemaker. Continuous stimulation was necessary for the next 14 hours and 45 minutes. During this time, the amplitude remained constant at 50 volts. At 4:30 P.M., the patient received 80 ml. of molar sodium lactate over ten minutes as recommended by Bellet and associates.[3] No changes were noted. At 11:45 P.M., on the twelfth day, regular ventricular contractions reappeared at a rate of 55 per minute, and these persisted for the next 35 days. Throughout each of the several periods during which the patient was dependent on the pacemaker, there were no Stokes-Adams attacks, the sensorium was clear, blood pressure was well maintained at 200/70 mm.Hg, and urine output was adequate. The patient tolerated the muscular contractions produced by the apparatus with a minimum of discomfort, although Demerol in 100 mg. doses was given periodically. Despite frequent change in the position of the electrodes, small ulcerations occurred beneath their site of application. These were treated with Aureomycin 1 per cent ointment, and quickly healed after the apparatus had been discontinued.

The patient remained in the hospital only for treatment of his allied conditions. During this interval, he received Adrenalin in oil 0.5 to 1.0 ml. intramuscularly every eight hours prophylactically.

On June 16, day 45, at 3:45 P.M., the patient developed a series of four Stokes-Adams attacks, each lasting fifteen seconds, with a pulse rate between attacks of 12 per minute and a blood pressure of 150/70 mm.Hg. The cardiac pacemaker was again started at 4:00 P.M. at a rate of 60 per minute with an amplitude of 50 volts. During the subsequent five hours, to prevent Stokes-Adams attacks, electrical stimulation was required for five periods totaling 160 minutes, the longest single application being one hour. Subsequently, spontaneous regular ventricular contractions occurred, and have persisted until the time of reporting.

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*Manufactured by Electrodyne Company, Norwood, Mass., and loaned through the courtesy of the Jewish General Hospital.

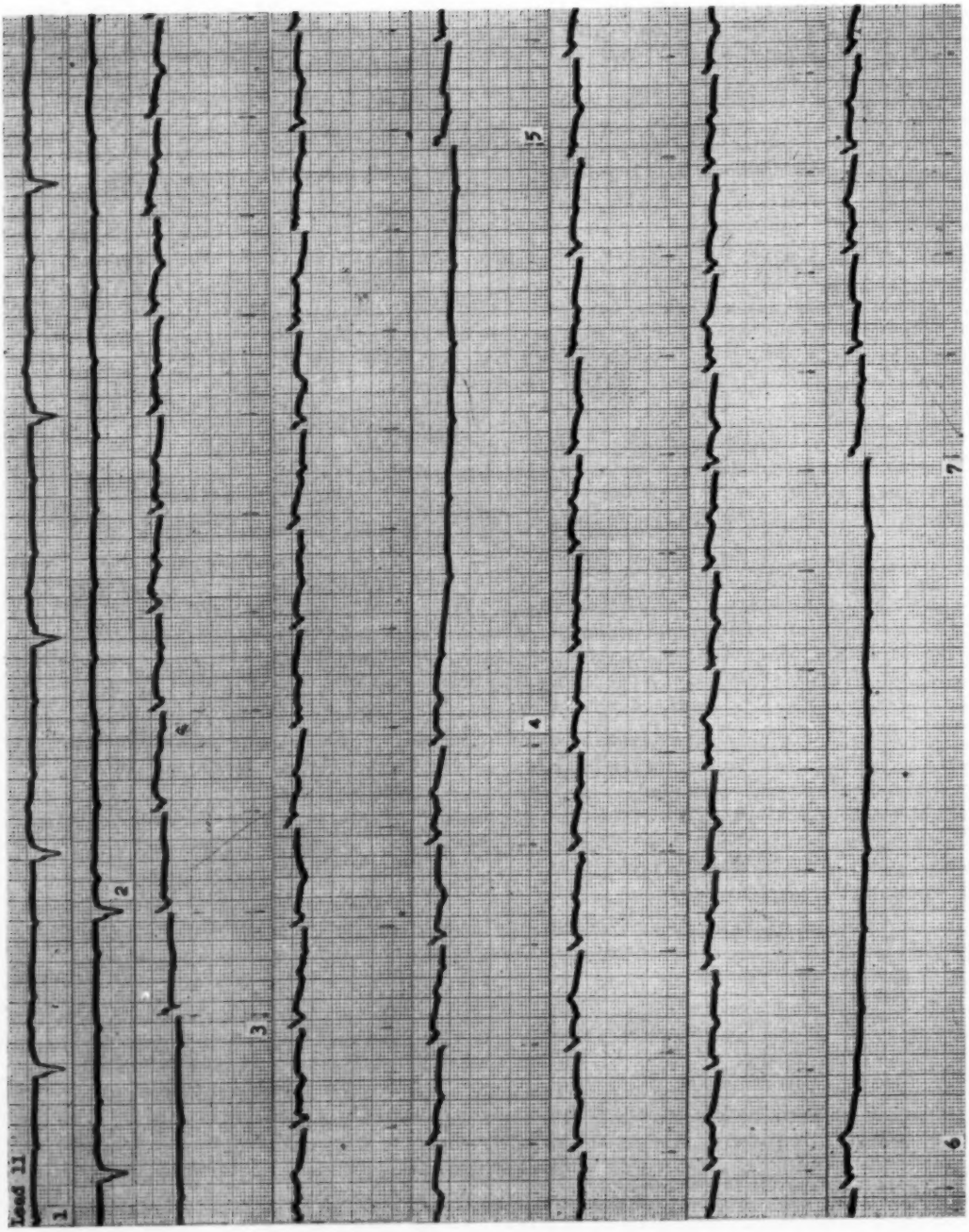

Fig. 1.—Continuous ECG tracing of Lead II taken on day 9. From *1* to *2*, complete heart block is seen with the ventricular rate slowing to 23 beats per minute. At *2*, spontaneous ventricular arrest occurred, and P waves only are observed. Electrical stimulation by the cardiac pacemaker was started at *3*, and although discontinued for brief periods at *4* and *6*, resumption of spontaneous ventricular contractions did not occur at this time.

DISCUSSION

The survival of this patient following prolonged ventricular arrest can almost certainly be attributed to external electrical stimulation of his heart. It was gratifying to observe the prompt and predictable response to stimulation by the pacemaker in the restoration of effective ventricular contractions. Although various drugs were used, none of these had any apparent immediate effect.

While the prognosis in patients with Stokes-Adams syndrome is dependent on the degree of underlying cardiac disease, the pacemaker may be able to tide the patient over critical periods of ventricular arrest, occurring in the course of their illness.

SUMMARY

A case of recovery, following several prolonged periods of ventricular standstill totaling 48 hours in all, is reported. Adequate circulation was maintained by the cardiac pacemaker, as designed by Zoll.

SUMMARIO IN INTERLINGUA

Es reportate un caso de recuperation post plure prolongate periodos de arresto ventricular, amontante a un total de 48 horas. Un adequate circulation esseva mantenite per medio del pacemaker cardiac, modello Zoll.

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ASSOCIATION OF COARCTATION OF THE AORTA AND PREGNANCY

Case Report

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WITH growth of knowledge concerning the pathophysiology and diagnosis of aortic coarctation, the association of this condition as a complicating feature of pregnancy has received increasing attention. A compilation[1] of the reported cases estimates their total number at ninety-six. In a somewhat earlier survey by Pritchard,[2] the autopsy frequency of coarctation was about 0.1 per cent. Therefore, some twenty thousand American women of child-bearing age may exhibit this complication, though its exact incidence in pregnancy is uncertain. Because of the limited experience on record, it has been difficult to arrive at a reliable opinion regarding proper management of the pregnancy. Pritchard has summarized the views which existed prior to his report in a thoughtful manner and attempted a careful reappraisal of the problem.

CASE REPORT

E.H., a 20-year-old Negro woman in the fifth month of her first pregnancy, reported to the Washington University Clinics on Feb. 16, 1950. She had been found to exhibit high blood pressure at the age of 12, when the diagnosis of coarctation of the aorta was first suggested. At 15 years of age she suffered an attack of pneumonia associated with migratory joint pains which was believed to be rheumatic fever. On examination, the blood pressure recumbent was 160/80 mm. Hg in the right arm. She weighed 147 pounds. Her uterus was enlarged to that of a five-month pregnancy. The retinal vessels showed considerable tortuosity. The heart was enlarged to the left. The second sound was split at the apex and there was a Grade 4 very loud, harsh systolic murmur heard with greatest intensity in the apical area, and a gallop rhythm. There was a palpable thrill over the carotid and subclavian arteries. Prominent pulsations were noticed along the vertebral borders of both scapulae and along the course of the inferior epigastric arteries. The femoral, popliteal, and dorsalis pedis pulses were not palpable. An intravenous phenolsulfonphthalein excretion test showed 35 per cent of the injected dye in the urine in fifteen minutes and 54 per cent in one hour. Roentgenogram of the chest (Fig. 1) was interpreted as showing right ventricular enlargement, an enlarged left auricle deviating the barium-filled esophagus, and notching of the posterior segments of the upper ribs bilaterally.

During the next two months the patient's pregnancy remained uncomplicated and her urine normal. Her blood pressure ranged between 150 and 200 mm. Hg systolic and 80 and 100 mm. Hg diastolic in both arms. Our impression was that of coarctation of the aorta and inactive rheumatic

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heart disease with mitral insufficiency complicated by pregnancy. On March 15, the patient was subjected to certain specialized studies; these included the direct recording of blood pressure from the right brachial and femoral arteries, estimate of volume pulsations from photoelectric plethysmographs, and registration of the ballistocardiogram on a Starr-type table (Fig. 2). The ballistocardiogram showed a shortened and deformed K wave, considered to be characteristic of coarctation by others.[3,4] Direct brachial artery pressure measured 195/110 mm. Hg; femoral artery pressure measured 120/85 mm. Hg. The abnormal saw-tooth appearance of the systolic peak and the delayed transmission of the femoral pulse has been found to be a characteristic deformity in coarctation.[5,6]

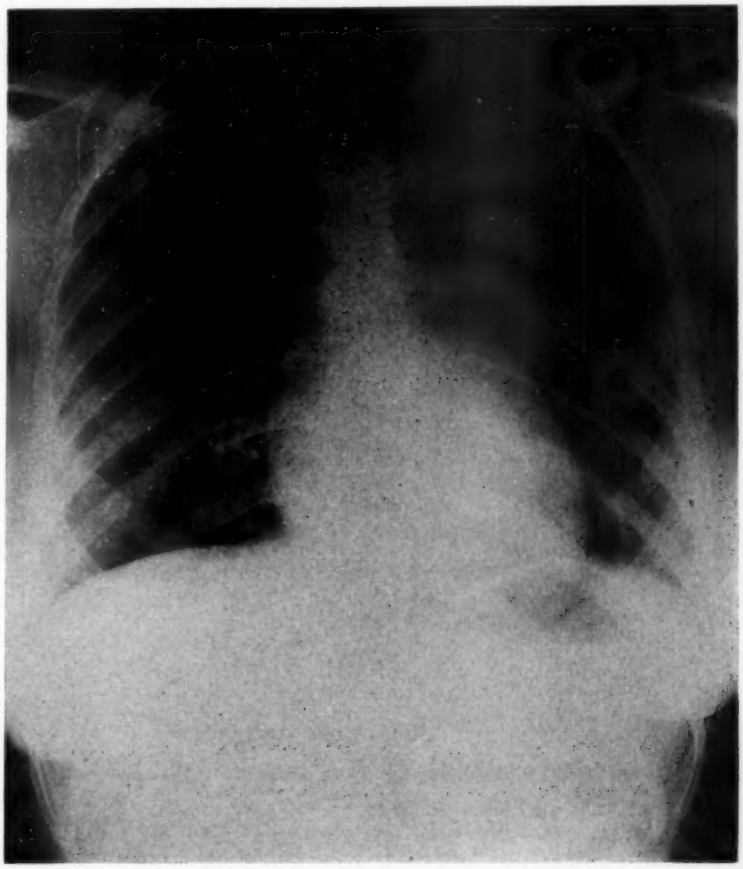

Fig. 1.—Roentgenogram of the chest. Note cardiac enlargement and notching of ribs.

On June 16, at the Chicago Maternity Center, a full-term infant was delivered via the vaginal route after a four-hour uncomplicated labor. The post-partum period remained uncomplicated, and the patient was discharged after five days and not subsequently seen.

DISCUSSION

The clinical and laboratory findings appear clearly to establish the diagnosis of aortic coarctation. It is less certain that the patient suffered from associated rheumatic heart disease, for findings identical with the auscultatory and roentgenologic evidence in support of this diagnosis have been noted in normal pregnant individuals.[7]

Recommendations for management have been a matter of considerable controversy in the past. The early literature suggested undue pessimism regarding this situation, since reports were often prompted by an unusual catastrophe, such as rupture of the aorta. If our estimates be correct, a great many uneventful pregnancies associated with coarctation go unrecognized or unreported. In deciding on proper management, it would be of considerable help to know if pregnancy increases the danger of rupture of the aorta or aggravation of pre-existent hypertension. Experience does not establish either of these points. With regard to the former, the suggestion has been made that rupture of the aorta is related to a curious pathologic entity (medionecrosis aortae idiopathica[8]) occurring proximal to the coarctation. If present, this disease would seem to predispose an aorta to catastrophic rupture; occurring in pregnancy, that event might not be clearly more than a coincidence. The incidence of associated medionecrosis is unknown.

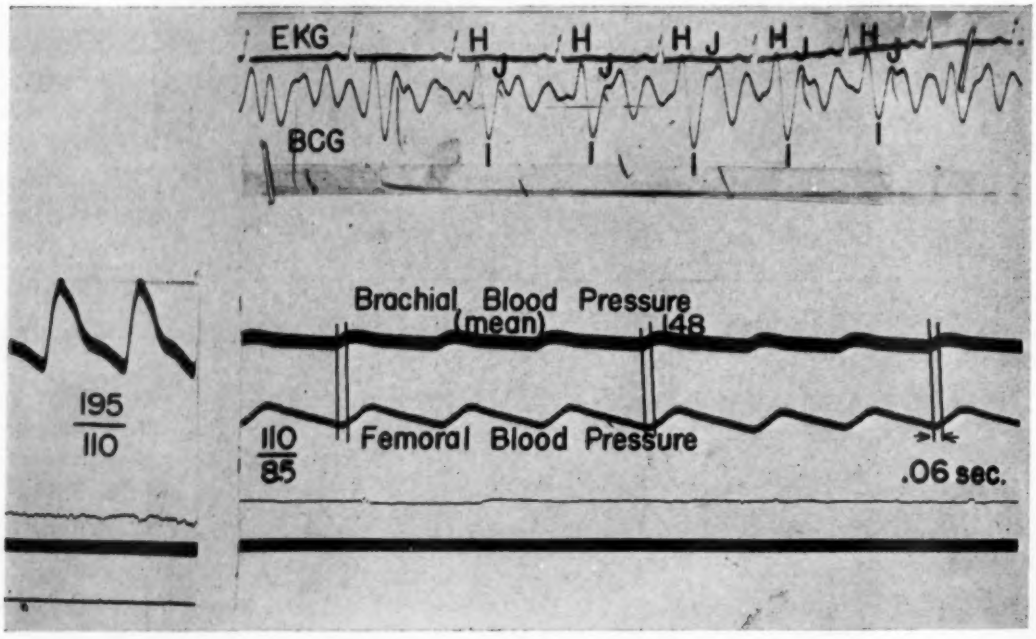

Fig. 2.—Record of ballistocardiogram, brachial and femoral pressure pulse. Note ballistic deformity consisting of absence of K stroke; blood pressure differences between arms and legs, delayed transmission and deformity of the femoral tracing.

Pregnancy complicated by coarctation probably should be managed primarily on the basis of the cardiac reserve without special implications other than the possibility of aortic rupture secondary to medionecrosis. A plan of management similar to those evolved for the more common forms of heart disease appears logical.[9]

SUMMARY

A case of coarctation of the aorta associated with an uneventful pregnancy in a 20-year-old Negro woman is reported.

SUMMARIO IN INTERLINGUA

Es reportate un caso de coarctation del aorta associate con un noncomplicate pregnantia. Le subjecto esseva un vintenne negra.

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FAT EMBOLISM OF THE LUNGS

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THIS condition was recognized for the first time by Zencker, in 1862, although Lower, in 1669, and later Magendie, in 1821, had produced it experimentally. The complete clinical picture was described by Warthin[1] and Groskloss.[2] The majority of papers deal with fat embolism appearing after severe trauma with bone fracture[3-9] and invasion of the blood stream with marrow fat. However, some of the experimental studies contribute a few facts that deserve to be pointed out.

The physical state of fat is important, in that only fat globules with a diameter higher than 12μ will stay in the alveolar capillaries. Probably that is the reason why in some disease states with high blood lipids, such as diabetic coma,[6] no lesion has been observed in the lungs. The amount of fat required to produce symptoms or death in humans varies considerably according to different authors: Lehman and Moore[3] estimate the figure to be 120 c.c., while a case has been observed in which fat embolism appeared after passing a catheter into the bladder using 2 c.c. of oil.[10] Experimentally[4,8] the injection of 0.9 c.c. per kilogram of body weight of neutral fat is capable of producing death in rabbits, which amount, other things being equal, would place the dose for an average man at about 60 c.c. However, in the same experiments, it was found that hydrolized fat was much more toxic, 0.07 c.c. per kilogram sufficing to produce death, which would amount to a dose of approximately 5 c.c. for the human, usual quantity used as vehicle for therapeutic, oily suspensions. Fatty acids seem to be the agents of tissue reactions and fat embolism would, therefore, produce symptoms in relation to the amount of acids liberated from the fat deposited in the lungs. These facts would explain the difference between neutral fat or oil embolism, and also the period free of symptoms observed after the accident, in relation with the hydrolisis of human fat and action of acids upon tissue.

After this initial asymptomatic period, there follows a rather constant clinical pattern[8]: shock, dyspnea with tachypnea, cyanosis, and profuse expectoration, without cough, of a pink fluid in which intra- or extracellular fat may be found. Thoracic pain is usually present and tachycardia and hyperpyrexia are constant findings. Signs of diffuse pulmonary edema are the outstanding findings in physical examination.

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There may be symptoms depending on embolism of other organs, such as the kidneys[8-10] or brain. Anemia has also been described.[6] If the patient survives, the lung picture may change to one resembling pneumonia with signs of consolidation with purulent and bloody sputum.

The underlying pathology is mainly pulmonary edema.[8,10,11] Embolic lesions are also frequently found in the kidneys, although usually there are no urinary symptoms.[8]

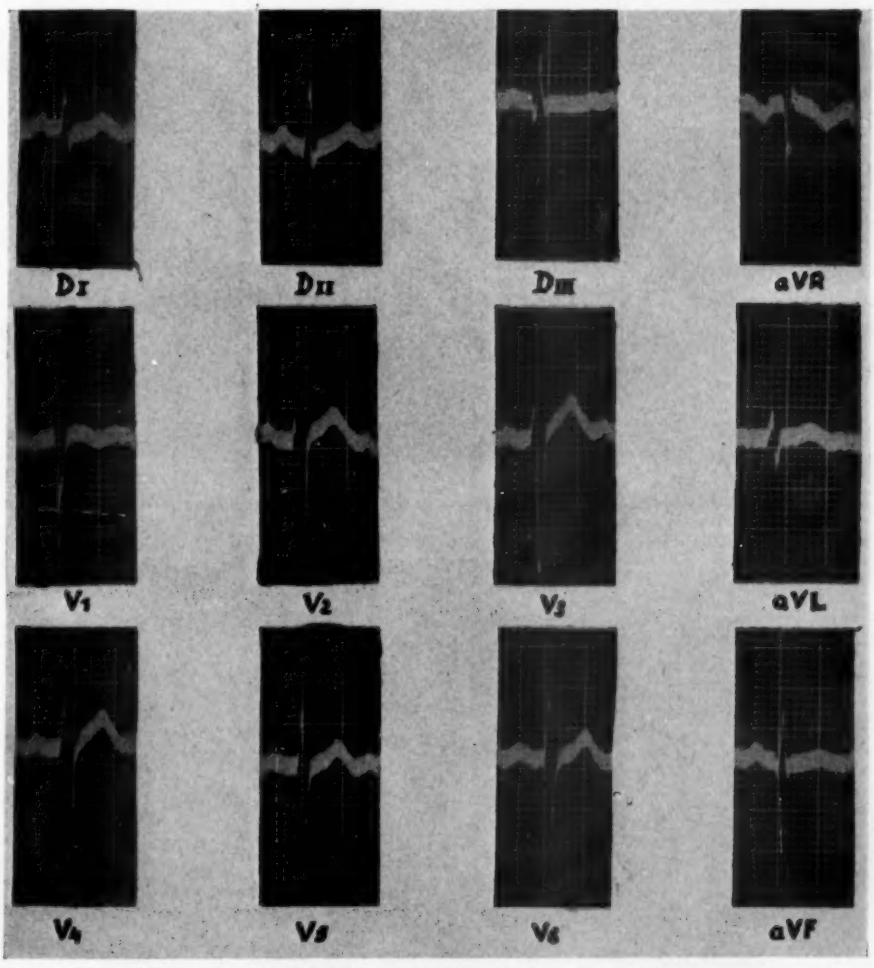

Fig. 1.—Electrocardiogram obtained the day after the fat embolism.

In the present case various functional studies were carried out which serve as a basis for discussion of the physiopathology of this condition.

CASE HISTORY

M.C.A., a 30-year-old woman, was admitted to the hospital suffering from multiple cystic hydatidosis of the liver. Surgical treatment was deemed impossible and a treatment with thymol in oil injections was prescribed. Following the fourth injection she complained of retrosternal oppression with severe dyspnea that lasted for a few minutes, accompanied by thymol taste in

Fig. 2.—Chest x-ray taken two days after the fat embolism; pulmonary edema is seen.

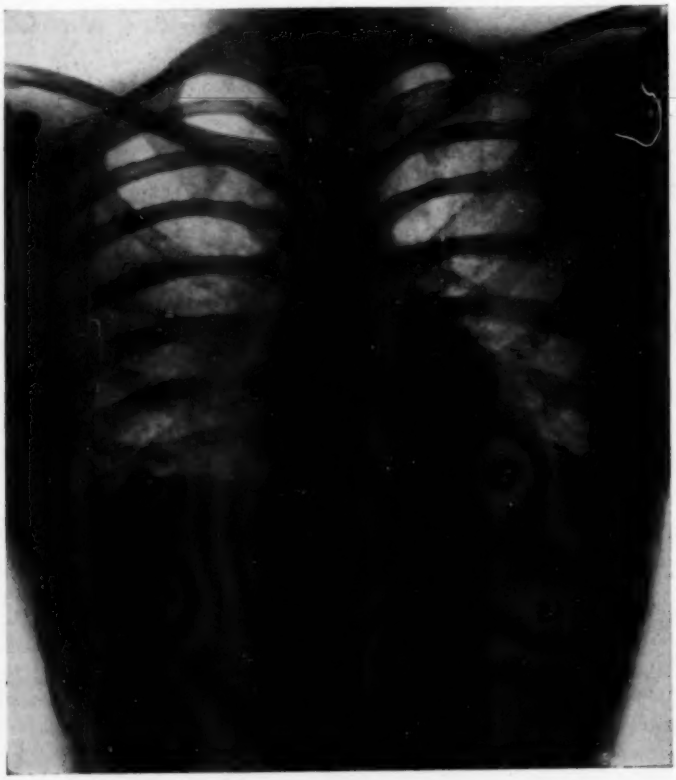

Fig. 3.—Chest x-ray immediately after recovery.

the mouth. Three hours later she again complained of dyspnea and expectoration of pink, frothy fluid, which reached 400 c.c. in the first day. She also had a very severe headache at that time. The patient, first seen by us on the following day, was found to be cyanotic with tachypnea (40 per minute). Physical examination revealed fine moist râles all over both lungs; temperature was 38° C., the pulse was regular at a rate of 140 per minute, blood pressure was 70/40 mm. Hg. Diuresis had been 300 c.c. for the past 24 hours. On that day the urine showed a specific gravity of 1.020 with traces of albumin. Blood urea was 46 mg. per cent, red blood cells 3,700,000 per mm.,[3] leukocytes 10,000 per cubic millimeter,[3] with 59 per cent polymorphonuclears, 6 per cent eosinophils, 31 per cent lymphocytes, and 4 per cent monocytes; hemoglobin was 10.7 Gm. per cent and hematocrit 32 per cent.

An electrocardiogram obtained at that time was considered to be within normal limits (Fig. 1). An x-ray of the lungs (Fig. 2) showed ill-defined round shadows extending throughout both lungs, predominant in the lower fields; the heart and mediastinum appeared normal. Previous x-ray of thorax was normal. Pulmonary function studies[12] were done three days after the accident, which showed (Table I) a markedly increased pulmonary ventilation with low vital capacity and normal maximal breathing capacity. There was a high ventilation of physiologic dead space. Alveolar ventilation and 0_2 alveolar pressure were higher than normal, due to the marked increase in minute volume of breathing.

Arterial blood studies showed severe oxygen unsaturation (Table II). With breathing "pure" oxygen (15 minutes), the saturation reached 100 per cent plus, with only 0.07 c.c. of dissolved oxygen[13] (normal, 2 c.c.). Arterial tension of CO_2 as well as pH were in the low normal values.

TABLE I

	FOUND		PREDICTED	% PREDICTED	
	8/20	8/31		8/20	8/31
Ventilation 1/min./m²	8.9	4.7	3.2	245	146.5
Vital cap. 1	1507	2867	3040	49.6	88.4
M. B. C., L./min.	84.2	99.3	90.0	93.6	110.0

	DEAD SPACE VENT. (% MIN. VOL.)	ALVEOLAR VENT. L./MIN./M²	$P_{A_{O_2}}$* MM. HG	A-a†
Normal	30	2.20	100	12
M.C.A.deA.	64.6	4.08	109	80

*Alveolar O_2 tension.
†Alveoloarterial gradient.

Right heart catheterization showed pulmonary arterial hypertension (Table III), which decreased to approximately normal values when breathing "pure" oxygen. Cardiac output, estimated by the Fick principle, was very high and decreased markedly with 0_2 breathing, as did right ventricular work.

Treatment was started with antibiotics, continuous oxygen therapy by tent, and noradrenaline,[14] 8 mg. per day, immediately after catheterization. Blood pressure increased in the first day of treatment to 98/58 mm. Hg and remained at that level. A diuresis of 2,000 c.c. was obtained that day and 2,500 c.c. on the following.

TABLE II

SAMPLE		O_2 CONTENT VOL. %		SATURATION		Pa_{O_2}*		HbO_2†
		AIR	O_2	AIR	O_2	AIR	O_2	
Femoral Artery	1	8.26	14.87	55.4	$100^{+0.07}$	29	—	14.73
	2	14.10	—	97.4	—	—	—	14.85
Pulmonary A.		5.09	10.96	34.0	73.8	20	39	—

	$BHCO_3$ VOL. %	CO_2H_2 VOL. %	$PaCO_2$‡ MM. HG	pH
Femoral Artery	51.92	2.71	39.0	7.39

*O_2 arterial tension.
†Oxyhemoglobin.
‡CO_2 arterial tension.

As the signs of pulmonary edema were still present, and dyspnea, tachypnea, and cyanosis reappeared when the patient was taken out of the tent, we decided to add adrenocorticotrophin, which was given intravenously in a dose of 25 mg. daily for three days, and resulted in immediate improvement of the pulmonary edema and disappearance of the cyanosis.

After eleven days, another pulmonary study showed almost complete recovery (Table I) with 0_2 saturation of arterial blood, 97.4 per cent breathing air (Table II), and normal x-ray of the lungs (Fig. 3).

TABLE III

		PULMONARY ARTERY	RIGHT VENTRICLE	CARDIAC OUTPUT*	CARDIAC INDEX
Pressures mm. Hg	air	56/22 (31)	48/9 (16)	9.65	6.35
	0_2	28/12 (20)	—	7.06	4.64

	TOTAL PULMONARY RESISTANCE†	RIGHT VENTRICULAR WORK‡
air	257	2.67
0_2	226.7	1.26

*l/min.
†Dynes–sec.–cm.$^{-5}$
‡Kg.–min.–M^2.

COMMENTS

In the reported case immediate symptoms common to all types of pulmonary embolism were present, but after a short, free period pulmonary edema of a protracted course was added. This development is a common occurrence in fat pulmonary embolism, due, probably, to the irritative action of fatty acids on the tissues or the neurogenic influence, as claimed by Cameron.[15]

Pulmonary function studies showed marked hyperventilation, which can be attributed both to stimulation of stretch receptors by increased rigidity dependent on congestion, and to that of chemoreceptors due to anoxemia. Vital capacity was low, as could be expected from the x-ray picture, while normal maximal breathing capacity showed that the majority of bronchi were free of obstruction. Alveolar oxygen pressure and ventilation were normal. The very low arterial oxygen saturation could be dependent on irregularities of ventilation-perfusion relationships or diffusion difficulty. Pure oxygen breathing eliminates the effects of unevenness of gas distribution and common types of diffusion block upon arterial tension. In our case, the lack of increase of dissolved oxygen up to normal values allows an estimation of venous-admixture of 33 per cent[16] of the cardiac output. Analysis of the alveolar-arterial final gradient, in these terms, is rather theoretical in this particular case, since alveoli which are full of edema fluid may not be ventilated, and under these conditions it is unimportant if one considers the effect on arterial blood as either venous-admixture or diffusion block. The pulmonary arterial hypertension could be due to the increased blood flow in the presence of some vascular obstruction by the emboli. However, the high grade of acute anoxemia, present in this case, is a more likely factor,[17,18] but more so when the decrease in pulmonary artery pressure with 0_2 breathing is taken into account, notwithstanding the fact that blood flow was also lower at that time. This decrease in cardiac output breathing 0_2 can be explained if we accept that its previous increase was conditioned by an attempt to keep the mean oxygen tension of tissues as near normal as possible[19] in face of low 0_2 content of arterial blood. When normality in mean oxygen tissue tension (39 mm. Hg) was temporarily obtained (Table II) blood flow approached near normal figures.

Treatment with adrenocorticotrophin was given to inhibit pulmonary exudative reaction to the irritant, and in view of the results obtained, we believe its use is advisable in this condition.

SUMMARY

A case of accidental oil pulmonary embolism producing shock and pulmonary edema is presented. Cardiorespiratory function studies showed hyperventilation, anoxemia, and pulmonary arterial hypertension with increased blood flow. Supportive treatment with noradrenaline, oxygen, and adrenocorticotrophin resulted in complete recovery.

SUMMARIO IN INTERLINGUA

Es presentate un caso de embolia grassiose pulmonar accidental, producente choc e edema pulmonar. Studios del function cardiorespiratori monstrava hyperventilation, anoxemia, e hypertension pulmono-arterial con augmento del fluxo sanguinee. Therapia supportative con noradrenalina, oxygeno, e adrenocorticotrophina resultava in recuperation complete.

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PARTIAL ANOMALOUS PULMONARY VENOUS DRAINAGE ASSOCIATED WITH MITRAL STENOSIS: REPORT OF A CASE WITH SURGICAL CORRECTION OF BOTH LESIONS

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ANOMALOUS pulmonary venous drainage into the right atrium and its tributaries occurs more frequently than previously believed. Since Brody[1] reviewed the literature in 1942, many cases of complete and partial anomalous pulmonary venous drainage have been reported.[2-8] With the ability to correct this lesion by surgical means, the importance of the diagnosis during life becomes apparent. Right heart catheterization and angiocardiography have been invaluable aids toward this end.[9,10]

A search of the literature failed to reveal a case in which anomalous pulmonary venous drainage associated with mitral stenosis was diagnosed during life, with correction of both lesions at the same operation. The diagnosis of anomalous pulmonary venous drainage into the left innominate vein was established by cardiac catheterization. Mitral commissurotomy for mitral stenosis and transposition of the pulmonary vein into the left atrium were accomplished successfully.

CASE REPORT

D.T., a 32-year-old white man, was admitted to Hahnemann Hospital on March 28, 1954, with a chief complaint of progressive exertional dyspnea and easy fatiguability. There was no definite history of rheumatic fever. A murmur was first detected in 1942 when the patient was examined by Selective Service. Symptoms began in 1944 when he developed fatigue and exertional dyspnea. In 1949, he first developed peripheral edema. He was placed on digitalis with good response. He stopped taking the drug two months later. In 1951 he had a second bout of congestive heart failure with hepatomegaly and peripheral edema. He also had hemoptysis at this time. He was placed on bed rest, digitalis, and mercurial diuretics. He improved on this therapy and gradually was returned to employment. The patient again stopped taking digitalis with return of marked dyspnea and orthopnea in November, 1953. He was placed on digitalis for the third time. Because of continuing disability and inability to return to work on this regimen, the patient was referred to the Bailey Clinic for possible surgery.

Physical examination revealed a well-developed, well-nourished young man in no acute distress. The blood pressure was 108/80 mm. Hg. Pertinent findings were confined to the cardiovascular system. Cardiac rhythm was regular except for an occasional premature beat.

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At the apex there was a mid-to-late rumbling diastolic murmur with presystolic accentuation ending in a sharp first sound. A blowing systolic murmur was heard here, but loudest near the sternum in the fifth left intercostal space where it was Grade 2 to 3. A short systolic murmur was heard at the pulmonic area. The second pulmonic sound was accentuated two-plus. No aortic murmurs were heard. The lungs were clear. The liver was not enlarged. One-plus pedal edema was present.

The electrocardiogram revealed a normal sinus rhythm with occasional atrial premature systoles and evidence of right ventricular hypertrophy and strain (Fig. 1*A*).

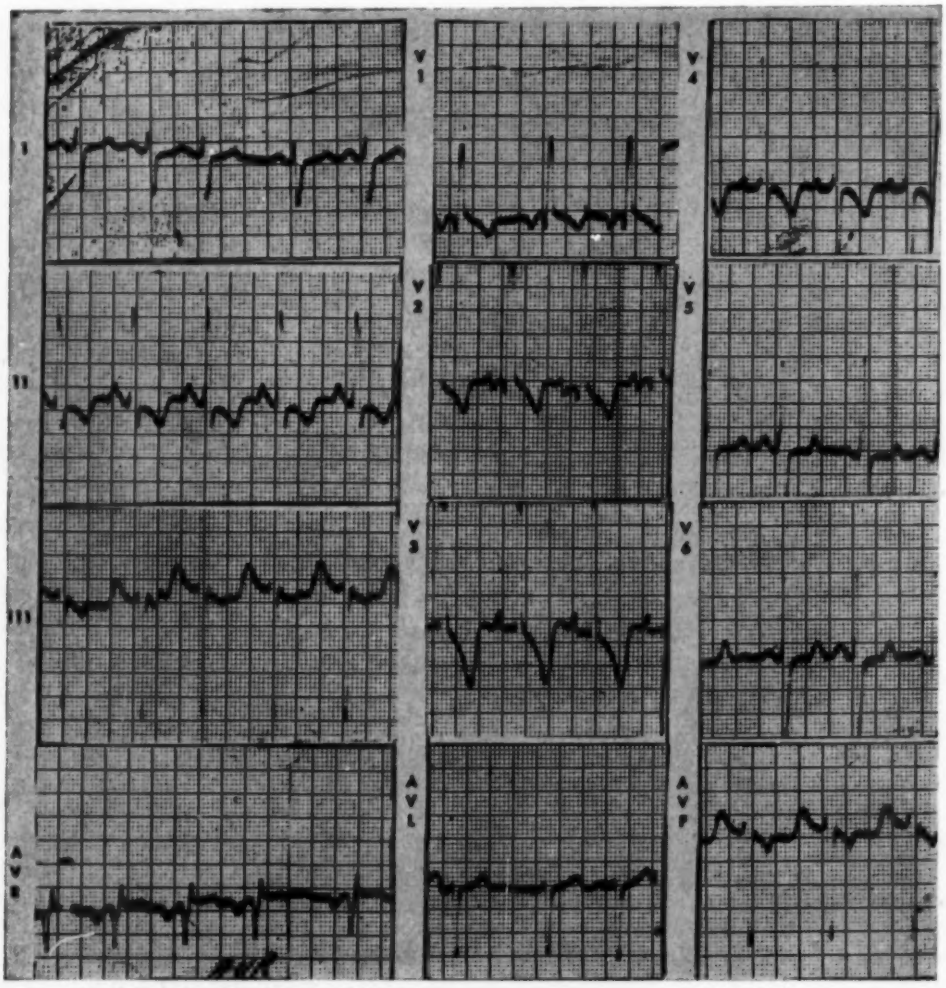

Fig. 1*A*.—Twelve-lead electrocardiogram taken preoperatively showing right ventricular hypertrophy and strain.

X-ray of the chest (Figs. 2*A* and 2*B*) revealed the heart to be enlarged two-plus in its transverse diameter. The right ventricle was enlarged two- to three-plus, the left atrium one- to two-plus, and the pulmonary artery, three-plus. There were increased pulsations of the pulmonary artery and hilar vessels on fluoroscopy. The pulmonary vascular markings were increased two- to three-plus.

The roentgen findings, particularly the marked enlargement of the pulmonary artery and its branches, and the vascular markings out of proportion to the increased size of the left atrium, suggested a diagnosis of mitral stenosis complicated by an associated atrial septal defect. Ac-

cordingly, right heart catheterization was done (Table I). These data revealed the presence of pulmonary hypertension compatible with mitral stenosis. There was no evidence for an intracardiac shunt from the blood samples obtained from the right heart chambers. However, the presence of more highly oxygenated blood in the superior vena cava than in the inferior vena cava suggested anomalous pulmonary venous drainage into the former. Generally we find the blood in the inferior vena cava to to contain more oxygen than that in the superior vena cava.

It was then decided to recatheterize the patient in an attempt to localize the point of entrance of the anomalous pulmonary vein or veins. Such information would be invaluable in a consideration for surgical approach of a combination of mitral stenosis and anomalous pulmonary venous drainage.

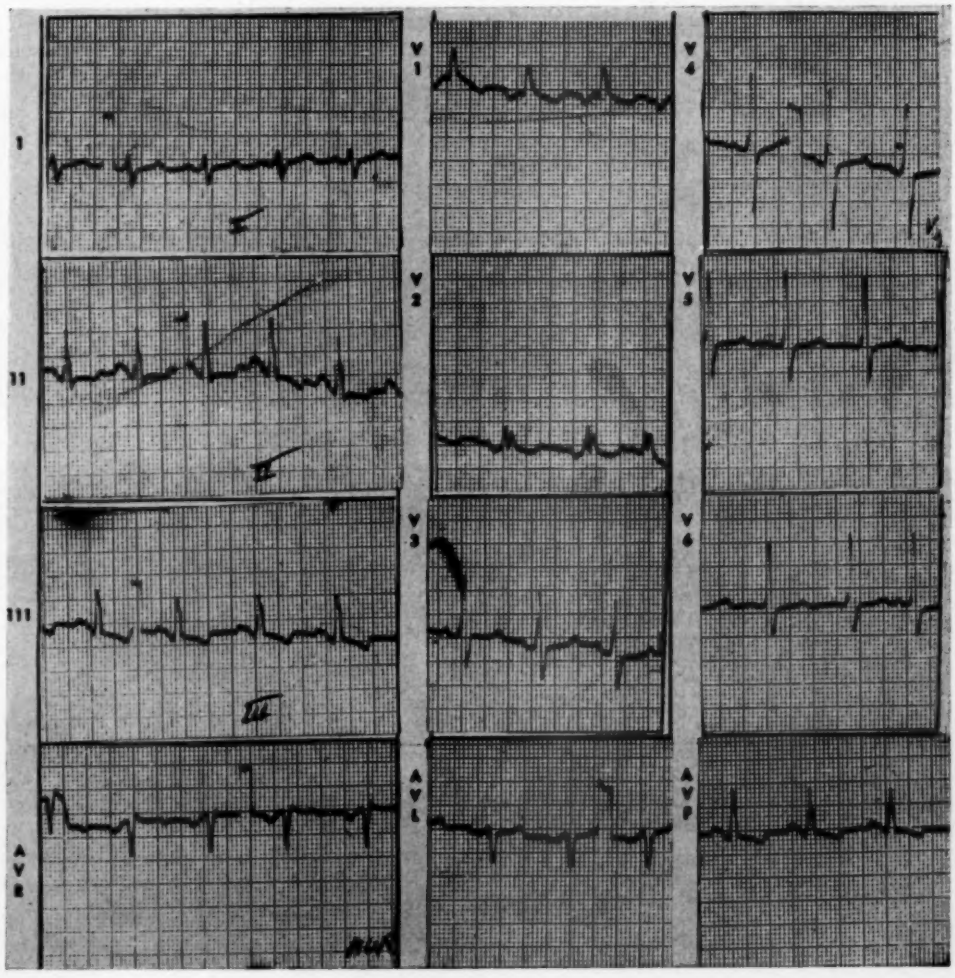

Fig. 1*B*.—Twelve-lead electrocardiogram taken one year following surgery. (See text.)

During the second catheterization (Table II) we were unable to enter an anomalous vein and successive samples from the superior vena cava, left innominate, and left subclavian veins proximal to the right atrium were withdrawn. At a point just proximal to the left sternal border the blood oxygen content suddenly fell 3 vol. per cent. This suggested the entrance of the pulmonary vein into the left innominate vein. Since pulmonary veins draining anomalously into the left innominate vein usually come from the left lung,[1] it was decided to enter the left hemithorax at surgery.

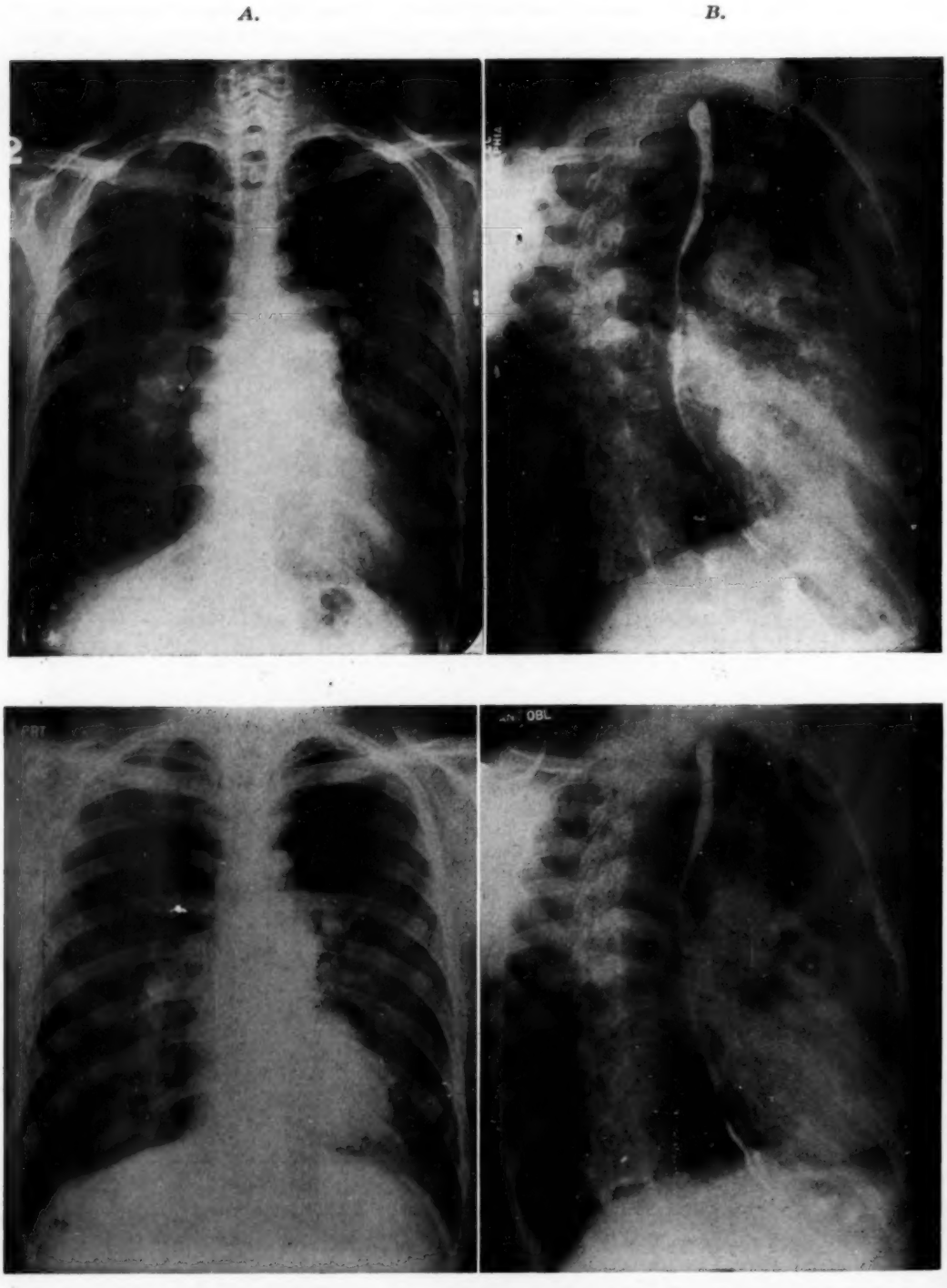

Fig. 2.—*A*, Preoperative roentgenograms (Anteroposterior view) showing enlargement of the heart and pulmonary arteries. *B*, Right anterior oblique view. Note posterior displacement of barium esophogram, indicating left atrial enlargement. *C*, Roentgenograms (Anteroposterior view) taken four months following surgery. Note decrease in size of heart and pulmonary artery segment. *D*, Right anterior oblique view. Barium esophogram is no longer displaced posteriorly.

TABLE I. RIGHT HEART CATHETERIZATION DATA (PREOPERATIVELY)

	OXYGEN CONTENT (VOL. %)	PRESSURES: SYSTOLIC / DIASTOLIC (MEAN)
Inferior vena cava	10.9	
Superior vena cava	13.3	
Right atrium		(4)
High	11.9	
Mid	12.6	
Low (near IVC)	11.9	
Right ventricle	13.0	63 / 5
Pulmonary artery	12.8	70 / 24 (38)
Brachial artery		120 / 50
Content	16.8	
Capacity	18.0	
Saturation	93.0	

Oxygen consumption	c.c./min.	148
Systemic blood flow	l/min.	2.5
Pulmonic blood flow	l/min.	3.7
Left-to-right shunt	l/min.	1.2

Surgical Procedure.—Surgery was performed on April 16, 1954. The left chest was opened in the third intercostal space. The left superior pulmonary vein was identified and dissection revealed its entrance into the left innominate vein (Figs. 3*A* and 3*B*). A finger introduced through an incision in the left atrial appendage revealed a tight mitral stenosis hardly able to admit the tip of the surgeon's finger (H. T. N.). With digital pressure alone this orifice was enlarged to admit one and one-half to two fingers. No regurgitation resulted. The finger was removed. Two patent ductus clamps were applied to the left superior anomalous pulmonary vein and cut. The distal end was closed. The proximal portion was anastomosed to the left atrial appendage (Figs. 3*C* and 3*D*). The chest was closed in the usual fashion.

TABLE II. OXYGEN CONTENT (VOL. %)

Inferior vena cava	11.1
Superior vena cava	
Low (near right atrium)	13.9
High (near innominate)	13.6
Innominate vein	14.5
Subclavian vein (mid clavicle)	10.2

Cardiac catheterization was repeated on Aug. 10, 1954. (Data in Table III.) There was a marked fall in the pulmonary arterial and right ventricular pressures. The pulmonary arterial pressure remained somewhat elevated in the face of a normal capillary pressure. The residual pulmonary hypertension is attributed to residual pulmonary vascular changes. The relationship between the blood oxygen content in the superior vena cava and the inferior vena cava is now normal. There is no further evidence for anomalous pulmonary venous drainage.

X-rays at this time showed reduction in heart size, pulmonary arteries, and vascular markings (Figs. 2*C* and 2*D*).

The electrocardiogram showed decrease in the amplitude of the R waves in Leads II, III, aV_F, and V_1 through V_3. The S-T segments became less depressed in these leads. The T waves, where formerly inverted, became either diphasic or upright. These findings would seem to indicate that there is less strain pattern present now. The R waves remained upright in the leads over the right precordium, indicating persistence of right ventricular hypertrophy (Fig. 1*B*).

Fig. 3*A*.—Photograph showing anomalous pulmonary vein draining left upper lobe of lung.

The patient was last examined on April 15, 1955, one year following surgery. He was asymptomatic. He no longer complained of exertional dyspnea or fatigue. Orthopnea was gone. He had no return of peripheral edema or hemoptysis. He had returned to work as a bartender one month prior and had no difficulty doing his job. Cardiac findings at this time revealed normal sinus rhythm. The mitral first sound was still sharp. The mid-diastolic rumble, though still present, was markedly reduced in intensity. The systolic murmur was no longer heard.

DISCUSSION

Although anomalous drainage of one or two pulmonary veins may be of little consequence, this lesion becomes clinically significant when it involves a whole lung, or both, or is complicated by other lesions. Most frequently, anomalous pulmonary venous drainage is associated with atrial septal defect. Rarely, as in the case herein reported, is it complicated by rheumatic heart disease.[12]

There is nothing pathognomonic in the clinical picture of anomalous pulmonary venous drainage. Some authors feel that x-ray of the chest may reveal the anomaly. This was not possible in our case. The electrocardiograms may be normal or show right bundle branch block or right ventricular hypertrophy and strain.

Most valuable in the diagnosis of this lesion has been right heart catheterization, angiocardiography, and dye dilution curves.[9,11,13]

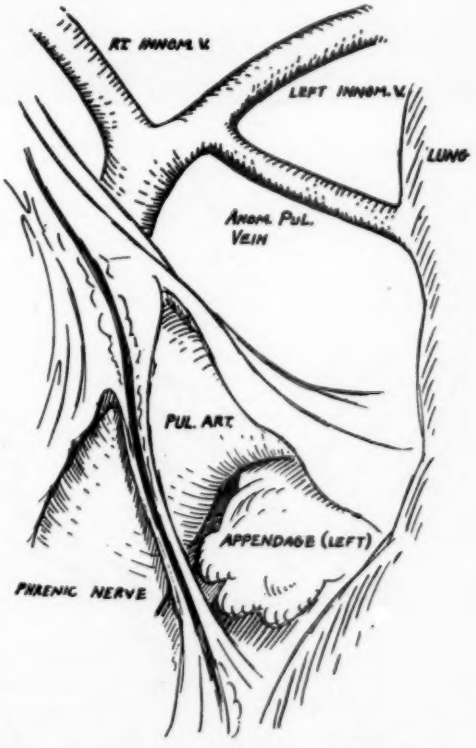

Fig. 3*B*.—Diagrammatic sketch of Fig. 3*A*.

Physiologically, anomalous pulmonary venous drainage into the right heart represents a left-to-right shunt. This results in an increase in the input load upon the right ventricle. The pulmonary blood flow is thus increased. The magnitude of the left-to-right shunt would be determined by (1) the amount of pulmonary tissue drained anomalously, (2) the nature of associated lesions, and

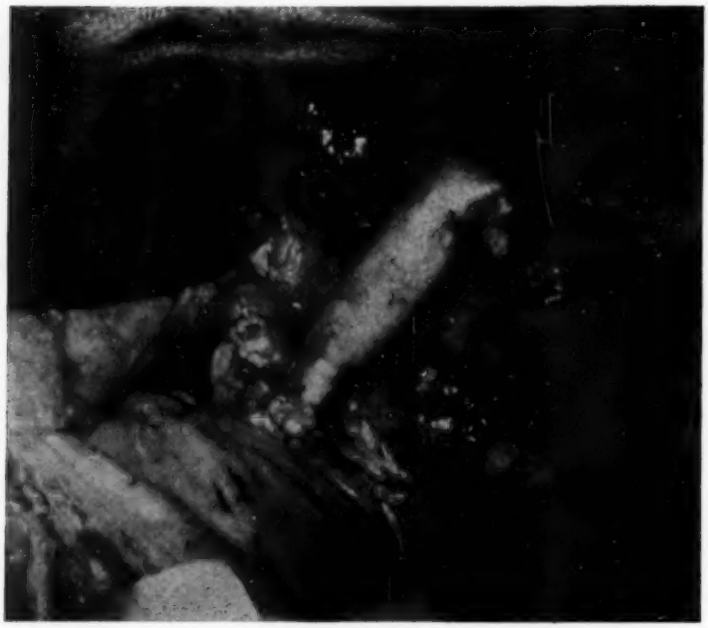

Fig. 3*C*.—Photograph showing distal end of anomalous pulmonary vein anastomosed to left atrial appendage.

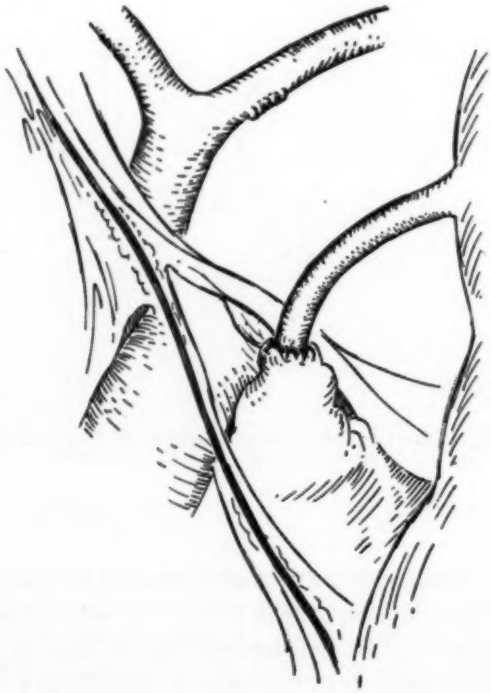

Fig. 3*D*.—Diagrammatic sketch of Fig. 3*C*.

(3) integrity of the pulmonary circulation. Thus in our case increased recirculation through the left upper lobe might be expected. The anomalous pulmonary vein entering the innominate vein was draining into an area whose outflow was not obstructed by a stenotic valve. The total resistance to flow is greater in the right lung and that portion of the left lung draining into the pulmonary veins entering the left atrium because of the presence of mitral stenosis.

TABLE III. RIGHT HEART CATHETERIZATION DATA—FOUR MONTHS POSTOPERATIVELY

	OXYGEN CONTENT (VOL. %)	PRESSURES: SYSTOLIC / DIASTOLIC (MEAN)
Inferior vena cava	12.2	
Superior vena cava	10.6	
Innominate vein	9.6	
Right atrium		(2)
High	11.0	
Mid	11.7	
Low	11.7	
Right ventricle		42 / 0
Mid	10.3	
High	11.5	
Main pulmonary artery	11.1	42 / 0 (28)
Pulmonary venous capillary	——	(3)
Brachial artery		128 / 70
Content	16.5	
Capacity	17.8	
Saturation	93 %	

Oxygen consumption c.c./min.	161
Systemic blood flow 1/min.	2.7
Pulmonic blood flow 1/min.	2.7
Pulmonary arteriolar resistance—dynes sec. cm.$^{-5}$	750

Therefore, it would seem likely that more blood would enter the left upper lobe drained by the anomalous pulmonary vein into the right atrium than if mitral stenosis were not present. This is all predicated upon the fact that the pulmonary vascular resistance is the same in all portions of both lungs. However, it is known that pulmonary vascular changes leading to increased resistance to flow occur in patients with left-to-right shunts due to atrial septal defect, ventricular septal defect, and patent ductus arteriosus. This may occur also in the course of patients with anomalous pulmonary venous drainage. The increased

pulmonary vascular resistance then acts as a protective mechanism to limit the increased blood flow through that lung, or portion thereof, which is drained anomalously. The fact that the pulmonic blood flow preoperatively in our patient was not greatly increased suggests that such was the case. Approximately 1.2 L. per minute was shunted through the lung being drained by the anomalous pulmonary vein. This represented about one-third of the entire pulmonic blood flow.

Surgical correction of partial anomalous venous drainage associated with atrial septal defect has been described by Neptune and associates.[14] This was a modification of the atrioseptopexy technique described for closure of atrial septal defects.[15] Subsequently Geraci and Kirklin[16] transplanted an anomalous pulmonary vein into the left atrium.

The simultaneous correction of mitral stenosis by mitral commissurotomy and transplantation of an anomalous left pulmonary vein into the left atrium in this case eliminated the left-to-right shunt at the level of the innominate vein and reduced the pressure within the pulmonary circuit. This was accompanied by marked clinical improvement.

SUMMARY

1. A case of partial anomalous pulmonary venous drainage into the left innominate vein associated with mitral stenosis is reported.

2. Mitral commissurotomy and transplantation of the anomalous vein into the left atrial appendage were successfully performed at one operation.

3. A follow-up of one year is presented.

SUMMARIO IN INTERLINGUA

1. Es reportate un caso de partial drainage pulmono-venose anormal a in le sinistre vena innominate, associate con stenosis mitral.

2. Esseva executate con successo in un sol operation commissurotomia mitral e transplantation del vena anormal a in le appendice sinistro-atrial.

3. Es presentate observationes post-operatori durante un anno.

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Announcement

The 1956 meeting of the AMERICAN GOITER ASSOCIATION will be held in the Drake Hotel, Chicago, Ill., on May 3, 4, and 5, 1956.

The program for the three-day meeting will consist of papers and discussions dealing with the physiology and diseases of the thyroid gland.

Book Review

ATLAS DER ELEKTROKARDIOGRAPHIE. By Rudolf Zuckermann, Leipzig, 1955, Georg Thieme Verlag, 500 pages, 387 figures.

The main purpose of the book is to introduce "Unipolar Electrocardiography" in Germany, which is, in the light of recent advances in electrocardiographic theory, somewhat of an anachronism. The author, however, refers also to spatial loop projections. The interpretation in terms of vectorprojection and in terms of local patterns as the basis of "Unipolar Electrocardiography" cannot be reconciled, since they rest on entirely different concepts. The author leaves it to the reader to solve this dilemma. It is surprising that Ashman's method is used for determination of spatial axes, which has, at best, some historical merit and is now superseded by the development of direct methods in spatial vectorcardiography.

The axes are given in terms of area axes instead of mean amplitude axes, but since both axes show a high degree of correlation, little, if any, additional information is obtained. Mean amplitude axes are much simpler to measure, and their normal limits are more reliably determined in a much larger material.

The book contains one of the largest ECG case collections published, well selected to represent a good cross section of the major aspects of clinical electrocardiography. The application of "Unipolar Electrocardiography" is shown mainly in individual ECG interpretations, but there is also a short introductory chapter. For the American reader, "Unipolar Electrocardiography" is, of course, nothing new.

However, even on the basis of the same concept, a different interpretation is possible in individual cases; electrocardiographic interpretation is traditionally a controversial subject. While discrepancies of opinion about one or the other ECG should be expected, the author's interpretations are, as a whole, quite speculative; and this reviewer would favor a more conservative interpretation.

The last part of the book contains a collection of animal ECG's including insects, fishes, reptiles, birds, and, among the mammals, that of the lion and puma.

E. S.